ELEMENTS OF PLANT SCIENCE

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BY

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FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1930

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

To
My Father and Mother

PREFACE

This book is an introduction to the study of plants. As far as it seems advisable, technical terms have been avoided; but we have tried to make the treatment scientific and necessary technical terms have been introduced with a definition and, generally, with an illustration.

The subject matter is arranged to meet the needs both of schools which devote only one semester to the study of plants, and of schools which have a whole year of botany. Schools which give only half a year to the subject are not likely to be supplied with microscopes, and, consequently, Part I is so written that it can be used without any microscopes, although a microscope for the demonstration of a few features is desirable. Even where microscopes are available, we believe the work should begin with the structures of higher plants which can be seen with the naked eye. Schools which devote a whole year to botany are practically always equipped with microscopes, and Part II assumes that each student has the use of a microscope or, at least, that not more than two students in the same section must use one microscope.

Since the book outlines a considerable part of the subject matter of botany, it could be used not only in high schools but also in other schools which have a beginning course. The laboratory suggestions could be amplified, supplementary readings could be assigned, and conferences could be made more extensive.

The conference should cover both laboratory work and a study of the text, and students should be encouraged to bring up any point which they do not understand. In our opinion, formal lectures have no place in high-school botany and should be used very sparingly in elementary college botany. Good material, thorough laboratory work, and reading of the text, with conferences prepared as carefully as a lecture, will secure the best results. Lantern slides of plants in their natural surroundings, described first by the teacher and then by students

in the conferences, will add to the knowledge and interest of any class.

Drawings should be made of all important features studied in the laboratory. Pencil drawings are convenient and shading does not require skill; but if a student wishes to use a pen, he should be encouraged. Line drawings and lettering are much neater when done with a pen, but shading is difficult.

The laboratory directions are intended to be suggestive. In different parts of the country different plants will be available. Teachers should use what they can find in the best condition.

Where teachers are not too heavily burdened, the laboratory directions will enable them to secure much of the illustrative material for Part I, especially after the first year. It takes a great deal of time to make the slides required for Part II, but in any large class there will be a few students who would enjoy this very critical and precise scientific work. The microtome, paraffin bath, staining equipment, slides, and covers would not cost more than $300, and most of the equipment is permanent. The laboratory directions would enable students to make slides with very little expense. Where such an arrangement is not made, the material and most of the slides must be secured from laboratory supply companies.

This book, with its laboratory work, should prepare the student for advanced work in most phases of botany. No special attention is given to agricultural botany, but we have tried to present the foundations upon which any sound study of that subject must rest.

We are indebted to many teachers for criticism and suggestions, but particularly to Prof. E. J. Kraus, who helped materially in the preparation of Chap. V. Miss Ethel Thomas made some of the pen drawings; Dr. Dorothy G. Downie and Dr. Grace Barkley made some of the negatives; and Dr. Paul Sedgwick and Dr. M. Dorisse Howe made some of the more difficult prints from the negatives. We are also indebted to Dr. S. Yamanouchi for criticism and advice. Corrections, suggestions, and criticism will be welcomed.

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THE UNIVERSITY OF CHICAGO,
CHICAGO, ILL.,
September, 1930.

CONTENTS

PART II

DEVELOPMENT OF PLANTS FROM THE LOWEST TO THE HIGHEST

INTRODUCTION

Plants were used for food, shelter, and clothing long before there was any scientific study of them, and today their uses have become innumerable; even the page from which you read is made from a plant. They have been cultivated and improved until many have become much more valuable than the wild plants from which they came; and some of the early improvements were due to primitive, but really scientific, methods. The same plant, under different treatment, may give rise to very different forms. Within historical times the Cabbage and the Cauliflower have been developed from the same plant, which, in its wild condition on the coast of Wales, does not look like either of them.

Advances in our knowledge of plants were slow until comparatively recent times. A hundred years ago there were no professors of botany in the United States. Even in the large universities the same man taught botany, zoology, and often other sciences. It has been said that Asa Gray, who died in 1888, was the first professor in the United States who was able to devote himself exclusively to the study of plants; but today there are hundreds who devote their entire time to the subject. A large university may have five or ten or even more professors of botany, who divide the subject, each taking some particular field, like structure, physiology, the relation of plants to their surroundings, plant breeding, plant diseases, and classification.

But whatever one's special interest may be, there are some fundamentals of plant science which all students should learn, no matter what special field they may choose later, and these fundamentals we shall try to present in language as free from technical terms as seems advisable. If a plant has a well recognized common name, like Oak, Beech, Maple, the common name is used; but where the common name is indefinite, like Water Weed or Pond Scum, the scientific name is used and is in *italics*. Occasionally, both names are given, sometimes one and some-

times the other being mentioned first. Even young children learn to say *Geranium, Begonia,* and *Iris* as easily as they learn Hollyhock, Poke Weed, and St. John's Wort.

The plants most familiar to us are those which have leaves, stems, and roots; and flowers, fruits, and seeds. These six organs of the flowering plants will be the subjects of the first six chapters.

PART I

STRUCTURES AND FUNCTIONS OF SEED PLANTS

ELEMENTS
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CHAPTER I

THE LEAF

The leaf makes the difference between the winter and summer landscape, and it manufactures into usable food the crude materials brought to it by the root, the stem, and the air.

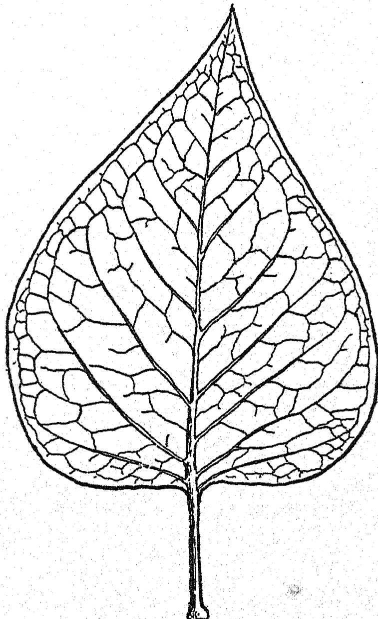


FIG. 1.—Leaf of Lilac, showing leaf stalk (petiole), blade, midrib and side veins. The margin is smooth (entire). Two-thirds natural size.

Forms of Leaves.—Leaves present infinite variety. No two, even on the same tree, are exactly alike; and yet they are so

characteristic that most plants can be recognized by their leaves alone.

A Lilac[1] leaf is as typical as any (Fig. 1). It has a thin flat blade, a midrib, numerous smaller veins, and a stalk. Since its margin is very even, botanists call it *entire* to distinguish it from margins which are not so smooth and even.

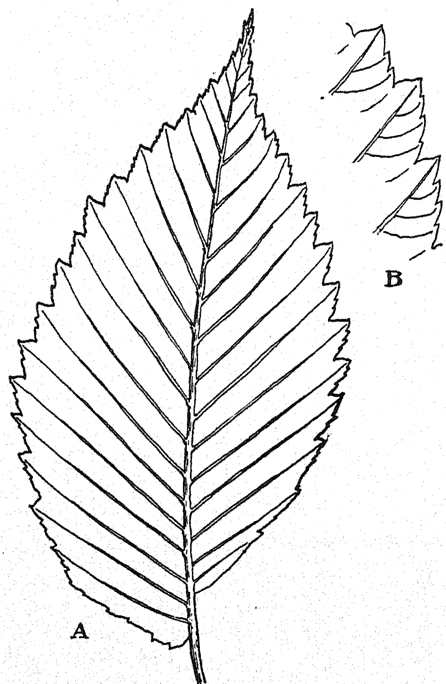


FIG. 2.—Leaf of Elm with saw-tooth (serrate) margin. *A*, natural size. *B*, three of the teeth enlarged and showing how the margin is determined by the veins.

Many of the veins can be seen with the naked eye, and it is these larger veins which determine the shape of the leaf. If the veins and the softer green parts of the blade grow at about the

[1] Scientific names, corresponding to the common names of plants, may be found in any good dictionary. "The Standard Dictionary" is particularly good for scientific names of plants. Manuals are good for the plants of their particular regions.

same rate, the margin of the leaf will be entire, as in the Lilac; but if the stronger veins grow faster than the softer parts, the leaf takes an infinite variety of shapes. The Elm and the Beech have saw-tooth (*serrate*) margins caused by the very strong side veins which grow so fast that the softer parts cannot keep the pace. The secondary teeth of the serrate margin, so conspicuous in the Elm, are caused by veins not quite so strong, which, nevertheless, are easily seen without a magnifier (Fig. 2).

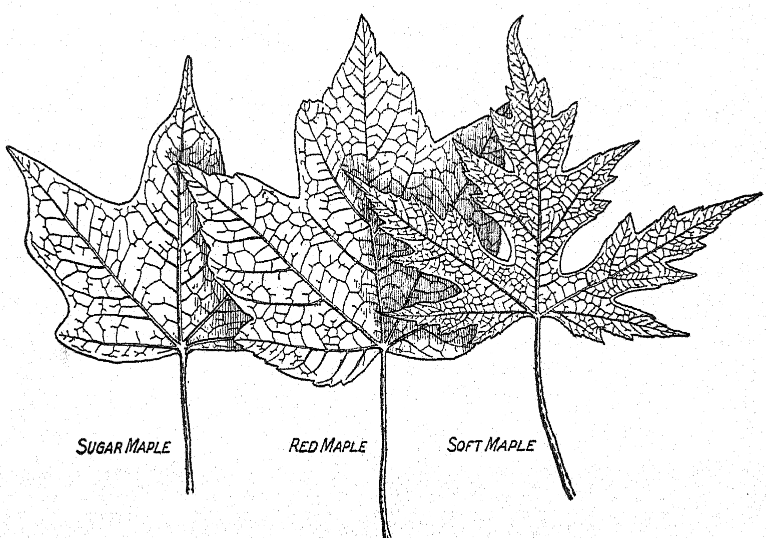


FIG. 3.—Leaves of Sugar Maple, Red Maple and Soft Maple, showing how the margin is determined by the veins. The midrib and two strong side veins, starting at the base of the blade, determine the general form of the leaf. One-half natural size.

In the Maple the midrib and two side veins are much stronger than the rest, and they determine the general shape of the leaf. Other veins not quite so strong cause the minor differences by which we recognize the Sugar Maple, Red Maple, and Soft Maple (Fig. 3).

In the Oaks there are two very common types of leaves. In the Red Oaks the margins are characterized by sharp points; while in the White Oaks the margin is smoothly lobed, so that the outline is more or less deeply wavy. Besides, there are Oaks,

like the Live Oak, in which the margins are nearly or quite entire (Fig. 4).

If the difference in the rate of growth of the principal veins and the softer parts is still more extreme than in the Red Oaks, the softer parts become separated as leaflets along both sides of the midrib, as in the Rose and Locust and in most Ferns (Fig. 5).

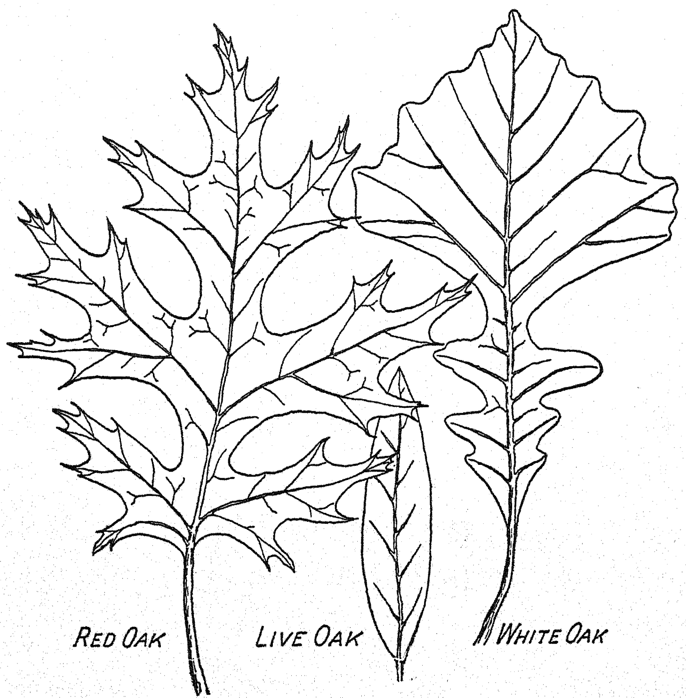


FIG. 4.—Leaves of Red Oak, White Oak and Live Oak, about natural size.

From the resemblance to a feather, such leaves are called *pinnate;* and they are also called *compound* to distinguish them from *simple* leaves, like the Lilac and Oak, which have the blade all in one piece.

When the leaflets of a compound leaf, instead of being arranged along both sides of the midrib, all start together at the top of the leaf stalk, as in the Horse Chestnut or Poison Ivy, the leaf is called *palmate,* from a fancied resemblance to one's palm and fingers (Fig. 6).

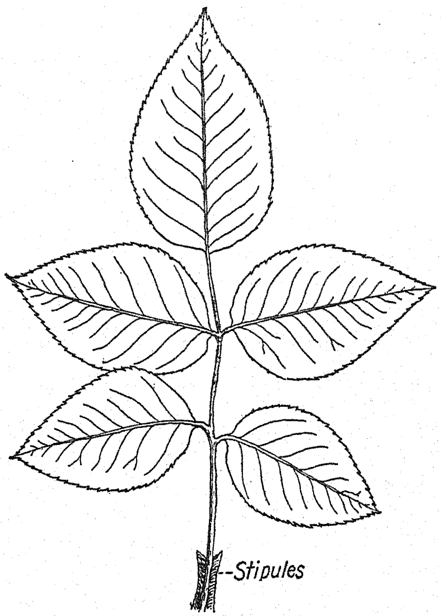


Fig. 5.—Compound leaf of the Rose, pinnate type, showing stipules. One-half natural size.

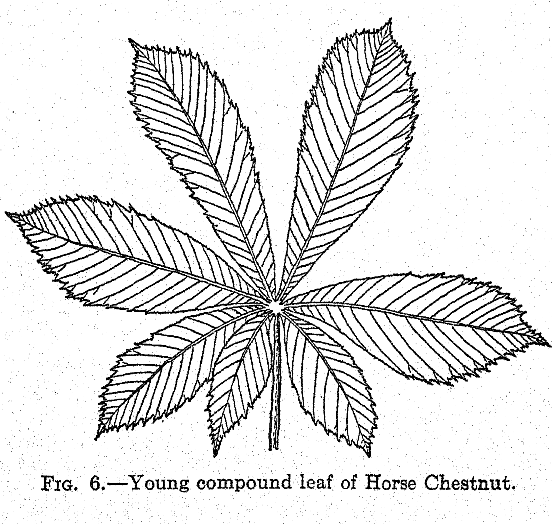


Fig. 6.—Young compound leaf of Horse Chestnut.

In many leaves, both simple and compound, there is a pair of leaflike structures, called *stipules*, at the base of the leaf stalk. The Rose and Red Clover furnish good examples (Fig. 5).

The leaf stalk is usually more or less roundish or crescent shaped in transverse section, but there are deviations from this

FIG. 7.—Rosin Weed, at Chicago, showing cupped (perfoliate) leaves. The leaves are about 5 inches broad.

pattern, as in the common Poplar, where the leaf stalk is a thin band. The simile, "quake like an aspen leaf," refers to the trembling movement of the leaf of the Aspen Poplar, which is constantly in motion, even when there does not seem to be a breath of air stirring. A glance at the leaf stalk of the Cottonwood Poplar or Aspen Poplar will show why the leaves move when other leaves are still.

Some leaves have no stalk at all, the blade resting directly on the stem. When such leaves are on opposite sides of the stem, the blades often look as if they had grown together around the stem. The upper leaves of the Honeysuckle show this condition. In some leaves of this kind, where the margins turn up and the leaf arises obliquely from the stem, cups are formed which hold water. In the Rosin Weed the cup may hold half a pint, and in some tropical plants the cups are much larger (Fig. 7).

In Grass, Corn, Cat Tail, Lily, Palm, Banana, and in thousands of others, the veins of the leaf are parallel. Naturally, such leaves are elongated and their margins are even, with none of the sharp points or rounded lobes which are found in leaves with a midrib and strong side veins. Parallel veins characterize a great group of flowering plants called *Monocotyls;* while the other type, with netted veins, characterizes another great group called *Dicotyls* (Figs. 8 and 1–7).

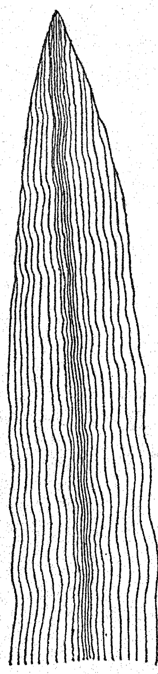


FIG. 8.—Leaf of Corn, showing parallel veins. One-half natural size.

Duration of Leaves.—Many evergreen trees, like the Pine, Fir, Spruce, and Juniper, have needle leaves, with only one or two veins and always with even margins. These leaves do not fall every autumn, but live 2 or 3 or even 10 years; so that the tree is always green, although some of its leaves fall every year. Nearly all cone-bearing trees are evergreen; but many plants outside of this group are evergreen, like the Live Oak and *Rhododendron* of our southern states. In warm countries, like New Zealand, so many trees and shrubs are evergreen that, in spite of the fact that there are large areas without cone-bearing trees, the landscape is green all the year round.

Large Leaves.—Some leaves are gigantic in size. Leaves of Tree Ferns are frequently 10 to 15 feet in length; and leaves of Palms sometimes reach a length of 40 feet, with midribs so large that natives use them for rafters in building their houses. In some Palms the bud scales, which are modified leaves, are so large

and thick that they serve as boards for the sides of the houses, and the roof is always a thatch of Palm leaves. In fact, Palm leaves are the principal building material for native houses in tropical countries, only the heavier timbers being made from Palm trunks or Bamboo (Fig. 9).

The circular leaves of the Amazon Water Lily, often cultivated in greenhouses and park lagoons, may be more than six feet in diameter and are so strong that one can throw on a cane mat, cut off the leaf stalk, and paddle around as if in a boat.

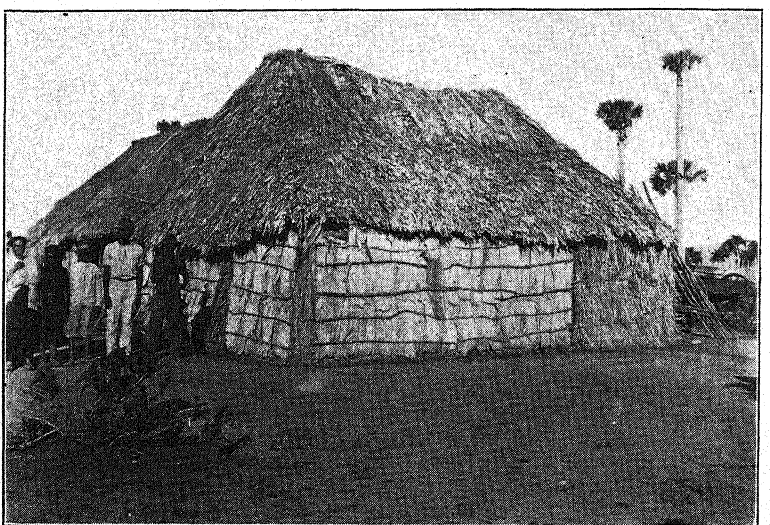


FIG. 9.—Hut in Cuba. The thatched roof is made of Palm leaves. The sides, looking as if made of boards, are made of the big leaves (*spathes*), which enclose the young flower cluster.

Surface of Leaves.—The surfaces of leaves are as varied as their shapes and sizes. Some, like the India Rubber plant and the Christmas Holly, are as glossy as if they were varnished; while others, like the Compass Plant are as rough as sandpaper. Some are covered with a bloom like that of the grape; some are velvety; some have short hairs which give them a whitish appearance, especially on the under side; and some, like the Mullein, are so densely covered with a layer of branching hairs that they appear woolly. Some, like the Nettles, have stinging hairs; and others have glandular hairs which secrete sticky juices.

Microscopic Structure.—The miscroscopic structure of leaves presents endless variety. The leaf is covered by a skin, or *epidermis*, which is best studied by stripping off a small portion, placing it in a drop of water on a glass slide, covering it with a very thin piece of glass, called a cover glass, and then examining it with a microscope. In the epidermis, especially that taken from the underside of the leaf, are small pores, called *stomata*, through which gases pass in and out, and through which water is evaporated from the interior of the leaf into the air (Fig. 10.) They are exceedingly numerous, as many as 20,000 to the square inch in the Apple, and some leaves have more. In the Lily they are not so numerous, but they are so large that they can be seen with a pocket lens. These stomata, which can open and close, control the movement of water and gases.

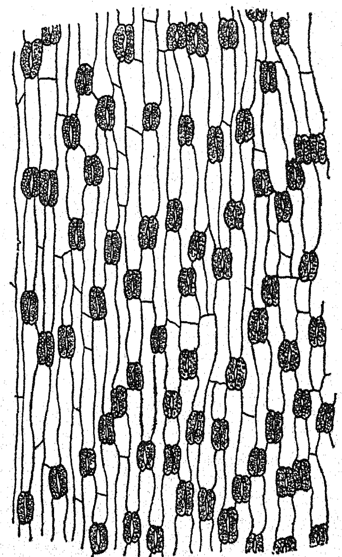


FIG. 10.—Lower epidermis of Lily leaf, showing stomata. × 20.

Beneath the epidermis are cells (see Fig. 11) which contain the living substance, *protoplasm*, and also small bodies containing the green coloring matter, *chlorophyll*, which enables the plant to manufacture food from inorganic substances. Plants without chlorophyll, like Mushrooms and Puff Balls, cannot manufacture food from inorganic substances, but must have it in the organic condition. In most foliage leaves thin sections show that the cells are more compact just beneath the upper epidermis and looser below, often with spaces between the cells. The veins, which transport the crude food materials and the manufactured foods, are prominent features in any section of a leaf (Fig. 11).

Ecology.—No part of the plant shows a greater range of adaptation to surroundings than the leaf. That phase of botany which deals with the relations of plants to their surroundings is called

ecology, and no part of this subject is more interesting or important than the study of leaves.

In some water plants the leaves below water are very different from those on the same stem just above the surface, the leaves below water being finely divided, while whose above have a sim-

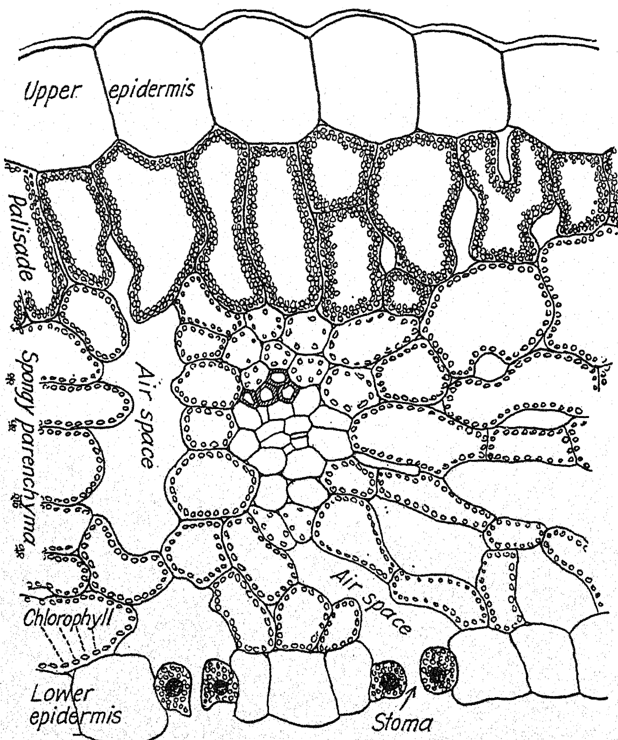


FIG. 11.—Cross-section of a small portion of a Lily leaf, showing lower epidermis with two stomata, compact cells (palisade) just beneath the upper epidermis, looser cells (spongy parenchyma) between the palisade cells and the lower epidermis, numerous air spaces, very numerous small bodies containing chlorophyll and, near the center of the figure, a cross-section of a small vein. × 230.

pler outline (Fig. 12). In the Knot Weed leaves floating on the water have a smooth, shiny surface, while those growing on the bank are so hairy that they were thought to belong to a different plant, until it was found that both were growing on the same stem.

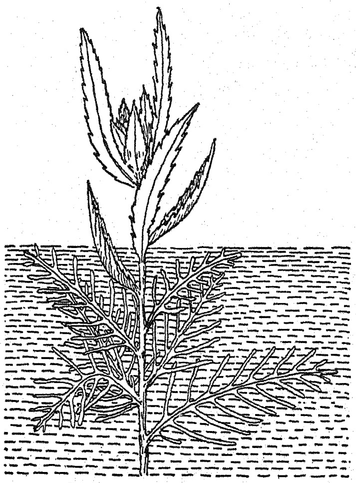


FIG. 12.—Mermaid Weed, showing the difference between leaves in the water and those in the air. About one-half natural size.

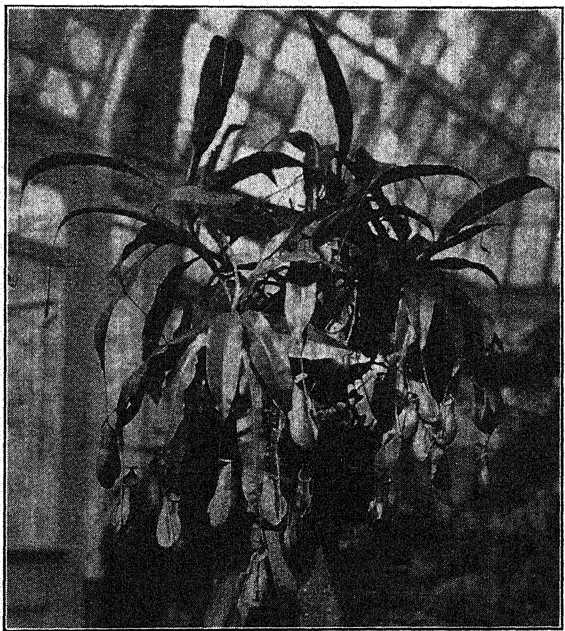


FIG. 13.—Pitcher Plant, in Phipps Conservatory at Pittsburgh, Pa.

Desert plants are likely to have tough leaves, with a resistant epidermis and stomata sunken below the general surface or protected by hairs, so that the wind causes comparatively little loss of water by evaporation. Fleshy leaves, so common in desert plants, are well adapted to store and conserve water. The Century Plant, with immense leaves several inches thick and

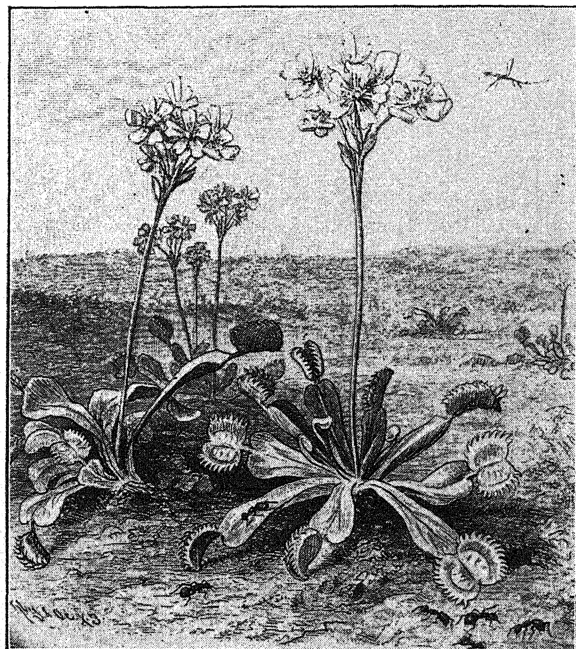


FIG. 14.—Venus Fly Trap. The two sides of the leaf snap together like a steel trap and catch the insects. (*After Kerner.*)

several feet long, holds its water through a long period of drought. Some kinds of Live-for-ever have fleshy leaves which hold their moisture with remarkable tenacity. One of these, called *Sedum spathulifolium*, growing on almost bare rocks in Puget Sound, was rolled up in a newspaper, packed with some dry specimens, and sent by parcel post to Chicago. When the box was unpacked three months later, the plant was still fresh and, set out in the greenhouse, promptly resumed its growth. One summer, Professor FRYE of the State University of Washington, pressed and

mounted a specimen of this plant and the next winter, found it growing on the herbarium sheet.

Leaves are sometimes curiously modified as in the Sundew, the Venus Fly Trap, and in various Pitcher Plants, all of which are called insectivorous plants because they catch insects and partly digest them (Fig. 13). In the Pitcher Plants the insect crawls down toward the liquid in the tubular part of the leaf,

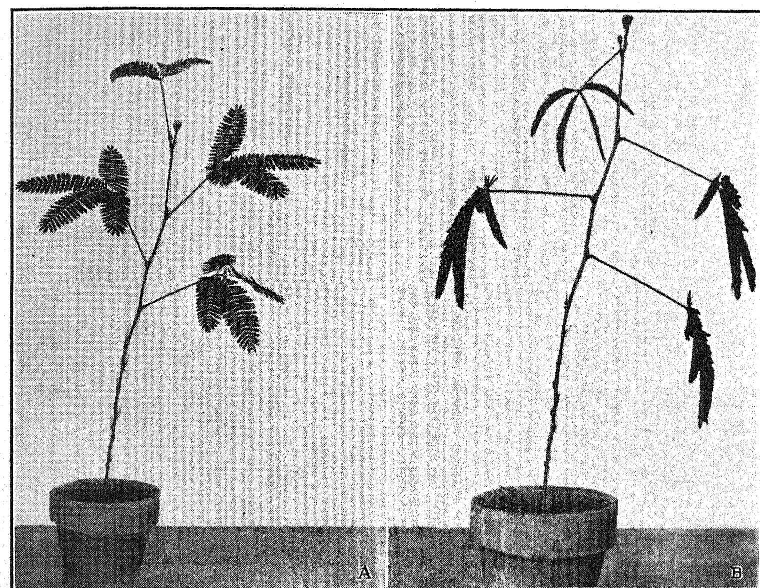


FIG. 15.—Sensitive Plant. The usual day position is shown in *A*; and the night position, or the position which it immediately assumes when touched, is shown in *B*.

where strong bristles prevent it from crawling back; so that any struggles only bring it nearer the fatal liquid. The leaf of the Venus Fly Trap has somewhat the shape of a small steel trap, which snaps shut when an insect touches it and holds the unfortunate intruder until it is digested (Fig. 14). The leaves of the Sundew do not close, but they are covered with hairs which secrete sparkling drops of juice as sticky as fly paper and more efficient, because they not only hold the insect but also digest it.

In many plants the position of leaves in daylight is very different from the night position. Clover, Locust, Peas, and Beans

furnish striking examples, with their leaflets expanded in daytime and folded together at night. In the Sensitive Plant, which is one of the show pieces of greenhouses, the night position is assumed instantly when the leaf is touched (Fig. 15). In the tropics when one walks through a patch of Sensitive Plants, it looks as if a mowing machine had cut a clean swath; but, in a few minutes, the normal position is resumed. In the daytime

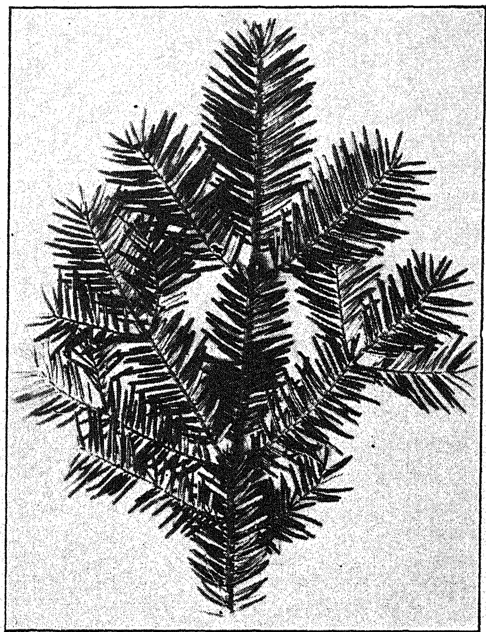


FIG. 16.—Leaf mosaic in Fir.

the expanded position enables the plant to do its work more efficiently, while the night position prevents some needless loss of water.

It is probable that the shapes of leaves and their arrangement on the stem are often determined by light, the leaves taking such a position as to present the best amount of surface to the sun. The striking arrangements of leaves which keep them from shading one another are called *leaf mosaics*. Ivy growing on walls of buildings affords an excellent example, and the needle leaves of the Fir shade each other even less (Fig. 16). Among house plants,

Begonias, especially those with large leaves, show a splendid mosaic arrangement if viewed from the direction of prevailing light.

Leaves of the Compass Plant show a remarkable reaction to light. From the north or south you see the edges of the leaves; while from the east or west you see the broad face of the blades. The leaves point almost as nearly north and south as the needle of a compass (Figs. 17 and 18).

Fig. 17.—Compass Plant (*Silphium laciniatum*), showing the broad face of the leaf as seen from the East or the West.

In some plants the leaves are so reduced that all resemblance to foliage leaves has been lost. In the Cactus the leaves are reduced to troublesome spines, and the normal work of leaves is done by the green stem. The pads of the Prickly Pear Cactus are not leaves, but flattened branches, which have stomata and chlorophyll; while the real leaves, the spines, do nothing at all in the manufacture of food. The Horsetail, also called the Scouring Rush, because the early settlers used it to scour kettles, has much reduced leaves and most of the normal work of the leaf is taken over by the green stem.

There are scores of other ways in which leaves have become modified. What has caused all these modifications? There are many theories, some of them supported more or less by facts; but one thing seems certain, the peculiar forms are modifications from a normal foliage leaf. It is not at all impossible that some of the theories, or parts of theories, as to the causes of the modifications may be proved to be facts.

Fig. 18.—Compass Plant (*Silphium laciniatum*), showing the edge of the leaf, as seen from the North or South.

Physiology.—That phase of botany which deals with the functions of various parts of the plant is called *physiology*.

Crude inorganic materials are manufactured into usable foods by all green parts of a plant, but most of this work is done by the leaves. We have already seen what may determine the external form of the leaf and how it may react to its surroundings. The microscopic structure is equally adapted to the work it has to do.

The external layer of the leaf, called the *epidermis*, has thousands of small pores (*stomata*), especially on the under side,

through which gases pass from the air into the leaf and from the leaf into the air (Fig. 10). The incoming gas is largely carbon dioxide and the outgoing is principally oxygen; so that plants purify the air not only by increasing the supply of pure oxygen but also by taking away one of its most dangerous impurities. At night, however, little or no carbon dioxide may be taken in, or the plant may even give off a little of this gas and take in a little oxygen; but any movement in this undesirable direction is so slight that the forest is a healthy place for your tent, and there is no doubt that the increasing number of shade trees in cities is good for the general health.

When the carbon dioxide has entered through the stomata, it is absorbed by the moist surfaces of the cells which make up the softer part of the leaf; and, once inside the cell, it is broken up into carbon and oxygen. The green coloring matter, chlorophyll, which gives the leaf, and often other parts of the plant, their green color, is the principal agent in the process. Besides the carbon dioxide from the air, water with various substances in solution is brought into the softer cells by the veins. Most of the carbon and some of the oxygen are built up into foodstuffs which contribute to the growth and nutrition of the plant, while most of the oxygen is given off into the air.

The breaking up of carbon dioxide into carbon and oxygen and the making of organic substances from carbon and water is called *carbon assimilation.* This process takes place only in the presence of chlorophyll and light.

There are many other elements in plants, at least ten of which are usually present. Iron is necessary to the formation of chlorophyll, without which organic substances cannot be built up from inorganic. Four of the elements, carbon, hydrogen, oxygen, and nitrogen, are so important that they once inspired a poet to write the stanza:

Vier Elemente	Four elements
Innig gesellt	Intimately mixed
Bilden das Leben,	Give form to life,
Bauen die Welt.	Build up the world.

An interesting experiment, proving that oxygen is liberated from the leaf, is easily performed, if plants growing submerged

in water are available. The water weed, *Elodea,* is exceptionally favorable for the experiment, but any of the plants used in aquaria will do. Place a quantity of the plant in a glass jar, invert a glass funnel so as to cover as many leaves as possible, then fill a test tube with water and place it over the stem of the funnel so that the water will not run out, and set the apparatus in bright sunlight (Fig. 19). Bubbles of oxygen rise and gradu-

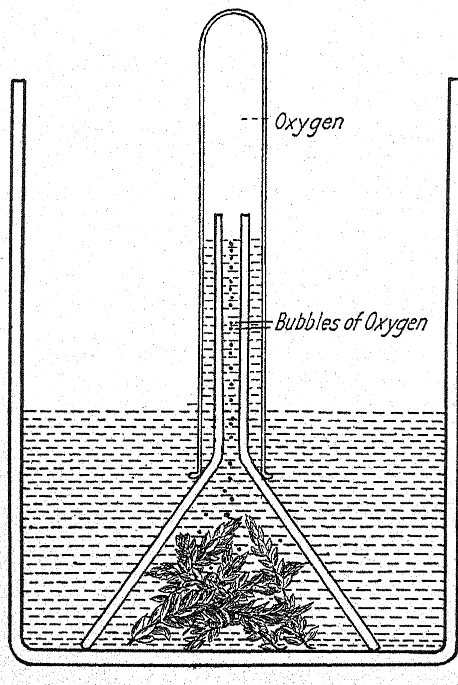


FIG. 19.—Experiment showing bubbles of oxygen being given off by a plant. The apparatus is a glass jar, a glass funnel and a test tube.

ally displace the water in the test tube. When the water is nearly out of the tube, there will be enough oxygen for a test. A match which has just been blow out, held at the mouth of the tube, will burst into flame and burn very brightly. If a large container is used and a large quantity of oxygen is secured, more impressive tests may be made. A wire which has been heated red hot, when inserted into the oxygen, becomes white hot and burns with wonderful brilliancy, and sparkling drops of melted

wire drop to the bottom of the vessel, which should contain an inch or so of water.

The first food to be formed is sugar; but sugar is easily changed into starch. That light and chlorophyll are necessary to transform the crude materials into usable food, can be shown by a simple experiment. Take any leaf which has white and green portions, like some Geraniums, or the drooping *Vinca*, which hangs so gracefully over the sides of window boxes; kill the leaf by boiling in water, soak it in equal parts of alcohol and water to remove the chlorophyll, and then place the leaf in a weak solution of iodine. The parts of the leaf which had been green will turn dark, indicating the presence of starch.

Stencil your initials through a strip of black paper about an inch wide and fasten the paper gently across a leaf so that the light will reach the leaf only through the stencil and outside the black band. After an hour or two, boil the leaf and proceed as before. There should be dark initials on a light band.

Cut the initials through two strips of black paper and fasten the paper on both sides of the leaf so that the initials will be opposite each other and will allow no light to pass, except through the initials. After a week, the part under the band will be white or yellowish, except at the initials where it will remain green. If the leaf be boiled and treated as before, there will be a light band with dark initials, showing that starch was produced only where there was light and chlorophyll.

Instead of the black band with initials, you can fasten a small photographic negative, gently but firmly, to a smooth green leaf and let it print for an hour or even two or three hours. The brighter the sunlight the better for this experiment. When the negative is removed, the boiling, alcohol, and iodine will show more abundant starch under the lighter parts of the negative and comparatively little under the darker parts. If the exposure is allowed to last for a couple of days, there may be a recognizable picture without any further treatment.

The sugar, manufactured from crude materials under the influence of chlorophyll and light, may be changed into starch and stored in the leaf or other green parts where it was made. Thick fleshy leaves, like those of the Century Plant, may store up immense quantities of starch. But much of the food manufac-

tured in the leaf is transported to other parts of the plant. Only substances which are soluble in water can be transported. Starch, which is not soluble, is transformed into sugar and, in this form, is transported to various parts of the plant, where it may be used or may be changed into starch and stored.

From materials coming in from the air and up from the roots, fats and oils and more complex substances are built up. Even living protoplasm is produced from non-living materials, just as the Cabbage we eat today soon becomes the brain with which we think. Botanists know some of the chemical changes which take place; but the change to the living from the non-living condition s still a mystery.

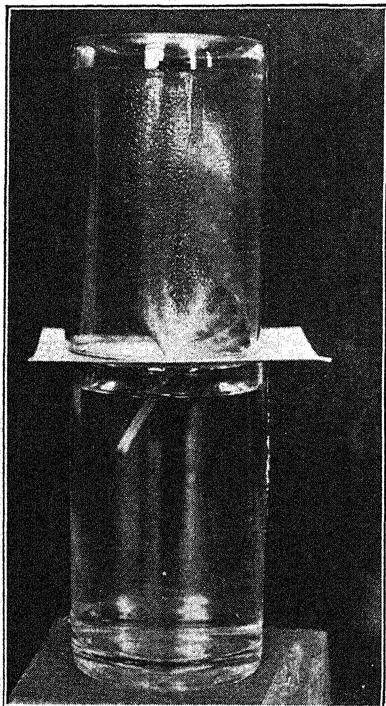


Fig. 20.—Transpiration. Experiment showing that water is given off by a leaf.

Leaves give off water to the air and the quantity is often very great. An average garden Sunflower plant will give off a couple of pounds of water on a bright dry day, but will lose only a few ounces during a dry night and, on a damp night, may not lose any. It is estimated that a large White Oak tree may give off 150 gallons of water in one day. On account of this evaporation of water from leaves, shade trees along the streets have a considerable influence upon the atmosphere, and forests have a decided effect upon climate.

On a hot dry day a thin leaf with little adaptation for retaining its water will lose water so rapidly that it wilts, unless a sufficient amount of water is supplied by the roots. That leaves give off water in sunlight can be shown by a simple experiment. Take

some leaf with a fairly long leaf stalk and push the stalk through a hole in a piece of stiff cardboard, immerse the leaf stalk in a tumbler of water, and cut off a little of the lower end of it under water. Invert another tumbler over the first, with the cardboard between them and the blade of the leaf in the upper tumbler (Fig. 20). Drops of water, evaporated from the leaf, soon appear on the inside of the upper tumbler. The process of giving off water in this way is called *transpiration.*

Uses of Leaves.—Of course, leaves are important on the table. Celery, Lettuce, Spinach, Onions, Rhubarb, Cabbage, and a host of others contribute greatly to our health and happiness. Leaves form the principal food of herbivorous animals. Many leaves are important in medicine, many are used in making string and rope, and we have already noted that the large leaves of Palms are the principal building material in tropical countries.

Diseases of Leaves.—Leaves, like people, are subject to innumerable diseases. Some of the ills can be cured, others can be partly remedied, but many seem to be incurable. If a leaf is diseased, it cannot do its full work of providing food for itself and the rest of the plant. Growth of the plant, as a whole, may be stunted, but the diseased part may grow enormously so that there are conspicuous galls, plant cancers, and various other abnormalities using up food which should go to other parts of the plant.

Some diseases, like the mildew on Lilac leaves, come late in the season and do little damage; but others, like the rust of Wheat and Oats, cause a loss of millions of dollars every year. A leaf of Wheat covered with rust cannot produce much food, and most of the food which it does produce is used up by the rust; so that little is left for the developing grain, and a small crop is the result.

It is evident that in many leaf diseases the real damage occurs in some other part of the plant, because of the diminished work of the leaf and the diversion of food by the diseased portion. In diseases of the Onion, Cabbage, and Celery, the leaf itself is the part of the crop which is ruined.

The U. S. Department of Agriculture spends millions of dollars every year in the control and eradication of plant diseases, and no part of the plant receives more of their attention than the

leaf. Colleges and universities are making scientific studies of plant diseases, and the time will come when doctors of plant diseases will be as thoroughly trained as doctors of medicine.

House Plants.—What decorative plants should you try to keep in the house? That depends more upon the keeper than upon the plants; but, in general, plants which will stand the most neglect and abuse are the most satisfactory.

The plant with a thick shiny leaf is more likely to succeed than one with a thin velvety leaf. The India Rubber Plant, the Screw Pine, and some of the small Palms stand at the head of the list. Ferns with smooth leathery leaves, Begonias, Geraniums, some kinds of Ivy, and some of the Lilies, which come from thick onion-like bulbs and which can be grown in a dish of gravel and water, often flourish, even in a steam-heated flat. The various kinds of Cactus are easy to keep and require little attention. When buying plants, it is well to ask the gardener or florist how often and how much each kind of plant should be watered.

Where most of the light comes from one direction, the growth of the plant may be very one sided. Every few days it should be turned around to keep the growth symmetrical.

People living in parts of the country where there is little or no snow and ice can easily keep plants which would need extreme care and skill where the winters are cold.

The parks of any city are likely to show what trees and shrubs and smaller plants are best suited to any particular locality.

The Fall of the Leaf.—As the life of a leaf draws to a close, a remarkable thing happens. It ceases to manufacture food, loses the green color of its working days, and may simply assume a dull, dead, drab color; but in many plants there is a wonderful variety of beautiful reds, yellows, purples, and pinks which constitute the autumn coloration. No mass of floral display could surpass the gorgeous spectacle of our mountain sides as the leaves have finished their work and are about to fall.

The fall of the leaf is as remarkable as its life and its coloration. In most leaves, some time before the actual fall, a thin layer is formed at the base of the stalk. This layer rapidly becomes corky and cuts the leaf off, so that you might say the wound is healed before it is made. The corky layer is very resistant to

water and cold; consequently, when the leaves fall, the plant does not suffer any damage.

Why do most leaves last only one season? Part of the answer lies in the fact that some of the mineral matter brought to the leaf is deposited on the inside of the cells like the incrustation on the outside of an old teakettle. Besides, the stomata become clogged and thus interfere with the normal work. This is especially true in large cities where the dirt, dust, and smoke add to the incrustation and clog the stomata so that leaves fall sooner than in the country. In a great city, evergreen leaves, like those of the Pines, which should last for several years, become greatly impaired the first season, and the second year they may fall. Since the tree cannot stand the strain of producing double the normal number of leaves, it soon dies.

Under normal conditions, a leaf has its youth, its middle age of hard work, and it dies of the infirmities of old age.

CHAPTER II

THE STEM

The stem is the leaf-bearing portion of the plant. Typically, it stands erect, displays the leaves in favorable positions, conducts crude materials to them, and transports food to parts where it is used or stored.

HERBS, SHRUBS, AND TREES

In a loose general way plants may be classed as *herbs*, *shrubs*, and *trees*, a classification based upon the stem. The Tomato, Turnip, Cabbage, Sunflower, Corn, and Banana are typical herbs. The Currant, Rose, Blackberry, and Lilac are typical shrubs. The Oak, Beech, Maple, Pine, and Palm are typical trees.

In the same loose general way herbs are small, shrubs are larger, and trees are the largest of all. But the Currant bush is a genuine shrub, although it is not more than 2 or 3 feet high; while the Sunflower and Giant Ragweed are herbs, in spite of the fact that they often reach a height of 10 or 15 feet. Most shrubs branch at or near the ground, while most trees have a trunk with side branches or only a trunk and leaves, with no branches at all. Shrubs are usually less than 30 feet in height, and trees are usually more than that; but occasionally shrubs reach more than 30 feet in height, while many trees, like the Thorn Apple and some Junipers, seldom reach a height of more than 10 or 15 feet.

Most of our familiar plants are easily classified as herbs, shrubs, and trees; but it is often difficult to draw a line between herbs and shrubs, and between shrubs and trees; so that, in many cases, it becomes a matter of personal taste whether a certain plant shall be called an herb or a shrub; or whether another shall be called a shrub or a tree.

Annuals.—Many herbs, like the Ragweed, Mustard, and the common garden Sunflower, live only one year and on that account are called *annuals*. They grow from the seed, produce stem, root, and leaves; then flower, fruit, and seed; and, finally, with

their work done and seeds ready for producing new plants the next year, they die. Annuals grow with great rapidity and the rapid growth makes great demands upon the food supply. The production of flowers and seeds is a still more severe drain, because most herbs produce great quantities of flowers and seed in proportion to their size, and they give nothing back to the plant, so that death often comes from exhaustion before the unfavorable weather arrives.

Biennials.—In *biennials*, like the Thistle, Turnip, Beet, and the common Evening Primrose, the plant lives two years. During the first year a crown or rosette of leaves is formed close to the ground and abundant food is stored in the root, which becomes large and fleshy. The second year the stem elongates, bearing scattered leaves and a great quantity of flowers and seeds, the production of which exhausts the supply of food stored in the root, and the plant dies. It is evident that undesirable biennial weeds can be destroyed by cutting them down the second season after they have nearly exhausted the food supply but have not yet matured any seeds.

Perennials.—Trees and shrubs live year after year and, because of this fact, are called *perennials.* Many herbs are also perennial, like the Goldenrod, Solomon's Seal, Jack-in-the-pulpit, Timothy, Kentucky Blue Grass, and nearly all ferns. They may die down to the ground in winter, but strong buds are ready to resume growth the next spring.

Trees.—The tree is the climax of all plant growth. In some groups of plants, as in animals, ancient forms, which became extinct millions of years ago, were immensely larger than any now living; but in the trees of today we have the largest plants that have ever existed. Since it is worth while, as a matter of general culture, to know something about them, we shall pay considerable attention to trees, especially the larger ones.

The Oak is so big and strong that it has won a firm place in poetry and prose. Fifty years ago in the region called the Western Reserve, just south of Lake Erie, Oaks six feet in diameter and more than a hundred feet tall were common; but most of them, together with the rest of the forest, were cut down and burned to clear the land for farming, and the few left standing were soon converted into railroad ties and butter tubs.

The Australian *Eucalyptus*, some species of which are widely cultivated, has become familiar everywhere by their long, drooping sickle-shaped leaves, as we see them in picture shows. In favorable places in Australian forests, occasional specimens are said to reach a height, of nearly 500 feet; but they are very slender

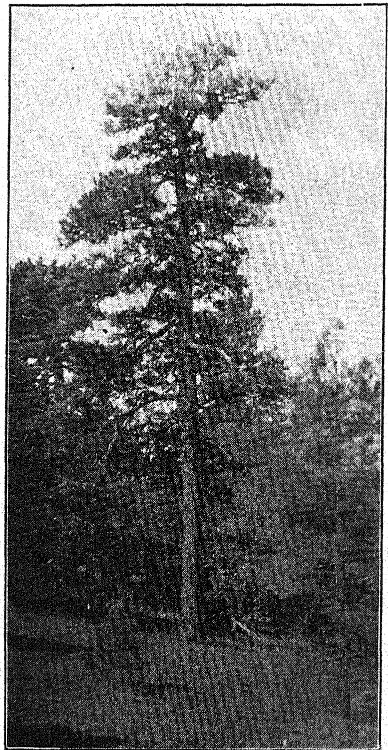


FIG. 21.—Western Yellow Pine, near Calaveras Grove, Calif. The tree is 6 feet in diameter.

and branch only near the top. Most of the *Eucalyptus* is stouter but less than 100 feet in height. It is the most abundant lumber tree of Australia.

The largest trees in the world belong to the cone-bearing group, called Conifers, of which the Pine is our most familiar example.

The Western Yellow Pine is usually 3 or 4 feet in diameter and more than 100 feet tall. The larger specimens are about 350

years old; but occasionally a tree reaches 8 feet in diameter, with a height of 200 feet, and the age may be as great as 500 years (Fig. 21).

The Sugar Pine of Oregon and California is still larger, often reaching a diameter of 4 to 7 feet, with a height of 160 to 180

FIG. 22.—Sugar Pine, near Calaveras Grove, Calif. This immense tree, about 12 feet in diameter, may be the largest Pine tree in the world.

feet and an age of 300 to 500 years. Occasional specimens are larger and may reach an age of 600 years. One large specimen, near the Calaveras Grove in southern California, is about 12 feet in diameter and nearly 300 feet high, towering like a giant above the surrounding forest (Fig. 22).

The Douglas Fir of our Pacific forests is even larger than the Pines. It is often 3 to 6 feet in diameter and 160 to 190 feet high, with occasional specimens 8 or 10 feet in diameter and

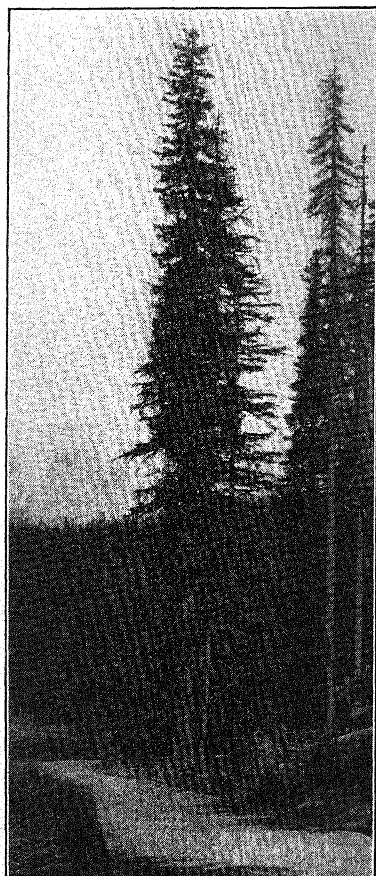


FIG. 23.—Douglas Fir, about 60 miles west of Seattle, Wash. The tree nearest the road is more than 200 feet high.

more than 200 feet high (Fig. 23). A tree 4 feet in diameter will be about 200 years old; 8 feet in diameter, about 375 years old; and one tree, 9 feet in diameter, had reached an age of 435 years.

The Kauri of New Zealand should always be mentioned in any account of big trees (Fig. 24). It sometimes reaches a height of 150 feet, with a diameter of 10 to 15 feet and, in rare cases, even 22 feet; its smooth trunk, as symmetrical as a Greek column, scarcely tapering at all, rises 50 to 80 feet before it begins to branch. Kauri gum, so important in making the higher grades of varnish, especially Dammar varnish, is the resin of the Kauri. Some of it is obtained from the living tree, where it sometimes hangs down from wounded portions, looking like great icicles 2 or

FIG. 24.—Kauri, North Island of New Zealand. *(From a photograph by Jones and Coleman.)*

3 feet long; but most of it is obtained by digging on the sites of ancient forests where the tree no longer exists. In spite of those practical people who can see in these magnificent trees only so many feet of lumber, hard and strong as oak and clear as the best grade of white pine, the government has been able to establish extensive reservations, so that there is no danger that the Kauri forests will become extinct.

Largest of all are the Big Trees of California, the Redwood and the Big Tree. The Redwood is often 8 to 15 feet in diameter and 190 to 300 feet in height; occasional individuals reach 18 to 20 feet in diameter, with a height of 325 to 350 feet. Some of them are 1,000 years old.

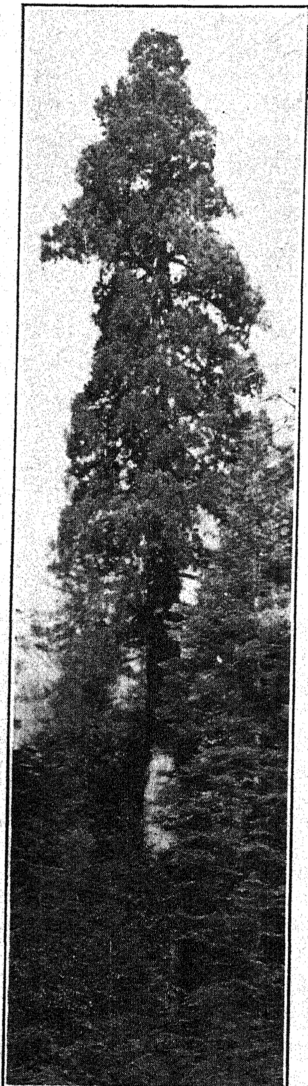


FIG. 25.—Big tree, *Sequoia gigantea*, Calaveras Grove, California. The tree is about 27 feet in diameter and more than 300 feet high.

The Big Tree is still larger than the Redwood (Fig. 25). Trees 250 to 280 feet high and 12 to 17 feet in diameter are common; here and there one finds specimens 300 to 330 feet high and 20 to 27 feet in diameter, measured at 10 feet from the ground. If measured lower down in the rapidly spreading buttressed region, much greater diameters can be obtained. Trees about 18 feet in diameter may be about 2,500 years old; and a few trees about 27 feet in diameter are known to be more than 4,000 years old. In the Calaveras Grove in southern California, a round house has been built on the top of the stump of a Big Tree. The top of the stump, about 6 feet from the ground, forms a floor 27 feet in diameter. Numerous national parks have been established to prevent both the Redwoods and the Big Trees from becoming extinct.

The Big Tree of Tule, not so well known because it is off the beaten track of tourists, may be the oldest living thing in the world (Fig. 26). It is a Cypress, called the Montezuma Cypress by the Mexicans, and is closely related to the Swamp Cypress of the southern United States.

It stands in the little churchyard of Santa Maria del Tule, about 250 miles southeast of the city of Mexico. More majestic proportions would be hard to imagine, for the trunk is 50 feet in diameter, and a regiment of soldiers could rest in the shade of its

widespreading branches. Twenty-eight people, with outstretched arms and with finger tips touching, can just reach around the trunk, which is as large where it begins to branch as it is near the ground.

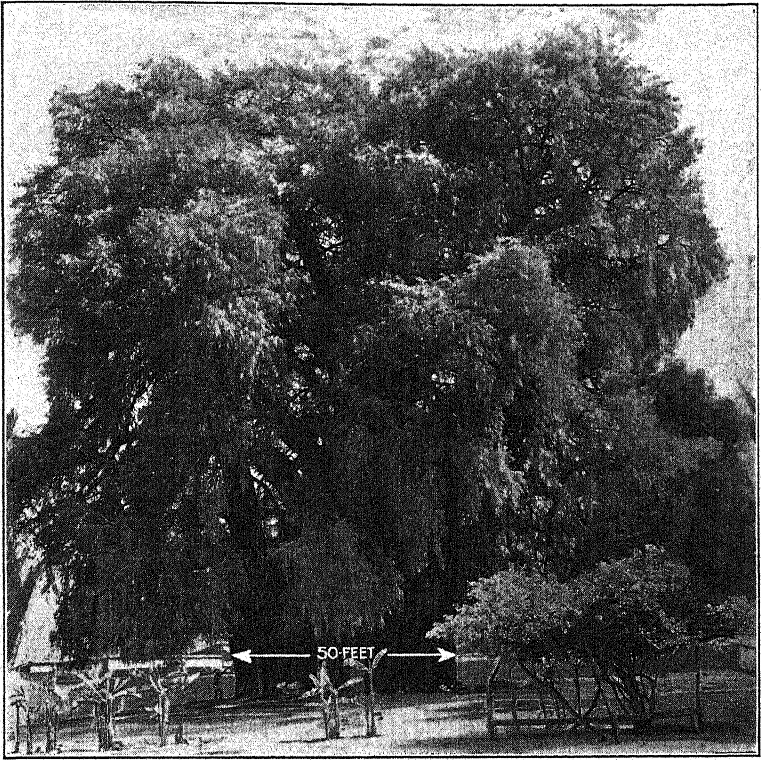


FIG. 26.—Big Tree of Tule (*Taxodium mucronatum*). This tree, near Oaxaca, about 250 miles south of the City of Mexico, is 50 feet in diameter and may be the oldest living thing in the world.

How old is the Big Tree of Tule? The age of a tree is determined by counting its annual rings. A piece of the trunk of a specimen less than 5 feet in diameter showed 200 rings on a radius of 1 foot. If the rings of the Big Tree have about the same width, its age cannot be less than 5,000 years; for it is well known that the largest rings are near the center and rings become narrower as a tree grows older.

Resting beneath the shade of the Big Tree and remembering its great age, one could hardly avoid thinking of the events which have occurred during its lifetime. Before the Pyramids of Egypt were built, it was a sturdy tree; and before Moses led the children of Israel out of the wilderness, it must have reached the usual size of its kind; when Rome was built, it must have been known as a Big Tree; in the days of King Arthur and his table round, its reputation as a giant must have been established; and ever since there have been Mexican traditions, Indians have made pious pilgrimages to the Big Tree of Tule.

Such an exceptional tree ought to be preserved. It is not in much danger from the natives, for they hold it in veneration, and the fact that it stands in a churchyard is an added protection. Still more effective is the wise foresight of the government which, knowing the vandal propensities of tourists, has stationed guards at the tree, so the big trunk will not be chipped for souvenirs or disfigured by having insignificant names carved upon it.[1]

To one familiar with the trees of the temperate zone, the Palm is the most striking feature of the landscape as he comes into subtropical and tropical regions. Tall, straight, and unbranched, splendidly symmetrical, with a great crown of leaves at the top, it is a favorite subject for painters and poets. Palms often reach a height of 100 feet with leaves 20 to 30 feet long.

Every tropical country has its "Royal Palm," but if one of them is more entitled to the name than another, it is the Royal Palm which attains its greatest beauty in Cuba (Fig. 27). The best known palms are the Cocoanut and the Date.

While Palms reach their highest development in the tropics, they flourish in South Carolina and the gulf states, and both

[1] The Big Trees of California, when described by European writers, are larger and taller than when measured by California botanists. Kerner says the height of The Big Trees of California sometimes reaches 426 feet and he gives the diameter of The Big Tree of Tule as 53 feet. He gives 65 feet as the diameter of The big Chestnut Tree on the slope of Aetna in Sicily, but this consists of five trees grown together. The European Sycamore is reported as reaching a diameter of 50 feet, with a height of 148 feet and an age of 5,000 years. These are in the list of "certified estimates." The sizes given in the text, except in this footnote, are fairly correct measurements.

native and introduced varieties are favorite decorative plants in California.

Besides the larger trees and palms, there are others which are interesting because they are unusual. The Morning Glory Tree of southern Mexico is as large as an apple tree, but it bears morning glories instead of apple blossoms. The Fuchsia Tree of New

FIG. 27.—Royal Palms (*Oreodoxa regia*) at Santiago de las Vegas, about 25 miles south of Havana, Cuba.

Zealand is also as large as an apple tree and its flowers, although small, look like those of the greenhouse Fuchsia.

Stranger trees than the Banyan and the Strangling Fig would be hard to imagine. In the Banyan of East India roots descend from the branches, and, when they reach the ground, take a firm hold in the soil and become trunks which put out more branches and leaves, and so the tree keeps spreading (Fig. 28). One specimen in the Botanical Garden at Calcutta, although only about

100 years old, has 3,000 trunks, more than 200 of which vary from 2 to 3 feet in diameter. The main trunk is 13 feet in diameter and 7,000 people can rest in the shade. It is only 70 feet high, but that is very high for a Banyan. The original trunk dies, but younger trunks keep forming, and the tree marches on. A big Banyan looks more like a grove than a single tree.

The Strangling Fig is a curious feature of the tropical forest (Fig. 29). The seeds seldom germinate on the ground but often

FIG. 28.—Banyan tree in Madura, India. It has more than 200 trunks. (*From a photograph by Irving Galloway, New York.*)

germinate among the leaf bases of Palms. Roots descend and become fixed in the soil, and the descending portion then puts out branches, many of which tightly encircle the Palm, finally entirely enclosing it and killing it, so that one sees only a big Fig tree; but if you should cut it down, you would find the Palm inside like a pith in a stem. The Palm shown in Fig. 29, although almost enclosed by Strangling Fig, is still producing a good crown of leaves; but the Fig is now well rooted in the ground and is producing vigorous branches and leaves which will soon enable it to surround the Palm so completely that nothing but the Fig tree

will be in sight. The appearance of the trunk of a victim at this stage is shown in Fig. 30.

Vines.—Many herbaceous and shrubby plants grow immensely in length without much corresponding increase in diameter. They are called *vines.* Being too weak to stand alone, they trail

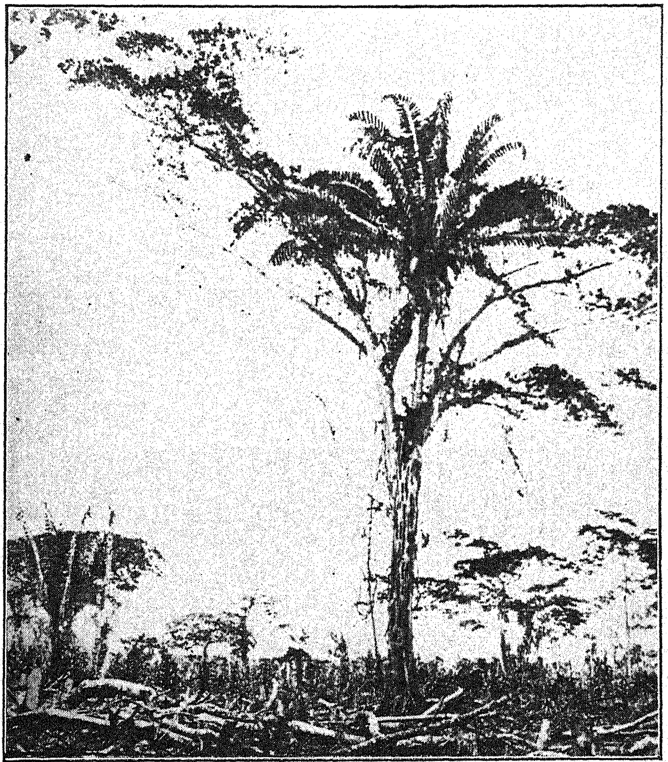


FIG. 29.—The Strangling Fig, at Tierra Blanca about 60 miles south of Vera Cruz, Mexico.

along the ground, clamber over other plants, or rise by twining around some support or by clinging to it in some other way, often by *tendrils,* which are curiously modified branches, as in the Pumpkin, or modified leaves, as in the Pea. When the tip of the long slender tendril comes into contact with a support, it coils around it; then the part of the tendril between the support and the vine begins to coil, and thus draws the plant close to the

support (Fig. 31). The Pumpkin is a familiar example of a trailing herbaceous vine, and the Morning Glory is just as good an example of a twiner.

FIG. 30.—The Strangling Fig, detail of lower part, just before the Palm becomes entirely enclosed.

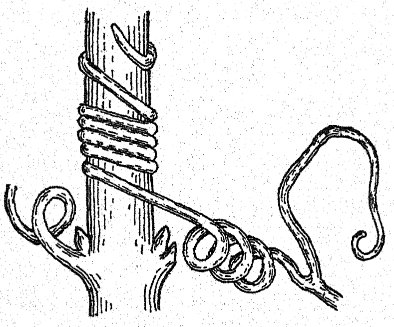


FIG. 31.—Tendril of Northern Fox Grape.

The various kinds of Ivy, on the sides of buildings, cling by little discs which become firmly fixed to the wall. The Poison Ivy, easily distinguished from harmless varieties by its three

leaflets, often becomes quite shrubby, climbing trees of considerable size. The harmless Virginia Creeper, with its five leaflets, also becomes quite large. The name, vine, was given originally to the Grape Vine, which often climbs to the tops of tall trees and is our largest vine.

Although vines are common everywhere, they reach their greatest display in the tropics, especially in the dense, tropical rainy forests. In such forests there are many plants which thrive in the shade, but among others there is a constant struggle to get into the light. Vines, by climbing and twining, may reach the tops of the trees and thus display their leaves in a position favorable for work.

In southern Mexico, about 70 miles south of Vera Cruz, one begins to encounter almost impenetrable jungles. A dense undergrowth, out of which innumerable herbaceous and shrubby vines scramble and climb and twine, makes a tangle through which the traveller slowly and laboriously cuts his way with a machete. A week later the trail is so overgrown that he has almost as hard a time to cut his way back.

Branching.—The branching of trees is so characteristic that many of them can be recognized in the winter condition, when all the leaves have fallen. The gracefully spreading branches of the Elm and the sharply rising branches of the Lombardy Poplar make it easy to recognize these trees.

There are two general types of branching. In one, the growth at the top of the stem is vigorous throughout the life of the plant, resulting in the development of a strong main axis or trunk, with weaker side branches. Nearly all cone-bearing trees, like the Pine, Fir, Spruce, Larch, and Hemlock, are good examples; and all vines belong in this class (Figs. 21, 25, and 27).

In the other type, the apical growth is weak or even suppressed, and the top of the tree consists of many strong branches, among which it might not be possible to recognize a continuation of the main trunk. The Elm, Apple, Box Elder, and most of our trees which shed their leaves every year, are good examples (Fig. 32).

While it is easy in many cases to see whether the main axis continues or breaks up into a spreading top in which it is lost or indistinguishable, there are all kinds of gradations. In Palms, Bamboos, and Tree Ferns, there is almost always no branching at

all. Some peculiar branches, like runners, suckers, stolons, and offsets, will be considered in Chap. VII.

Rhizome.—Many stems are underground, only the leaves appearing above the surface. The rhizome is a very common

FIG. 32.—Elm tree, showing type of branching.

stem of this type. The *rhiz-* part of the word means root, and the name was given because these stems usually lie beneath the surface and behave somewhat like roots; but they bear true roots and produce leaves. Roots do not produce any leaves, and so it is not difficult to decide whether an underground structure is a rhizome or a root.

The May Apple, Solomon's Seal, and the Bracken Fern furnish familiar examples of rhizomes. In the Solomon's Seal, one large

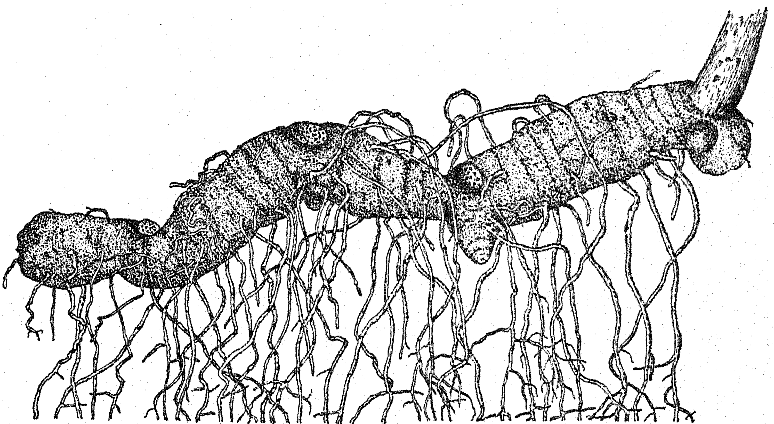


FIG. 33.—Rhizome of Solomon's Seal, showing lower part of leaf stalk and three scars ("seals") where leaves of the three preceding years have broken off. One-half natural size.

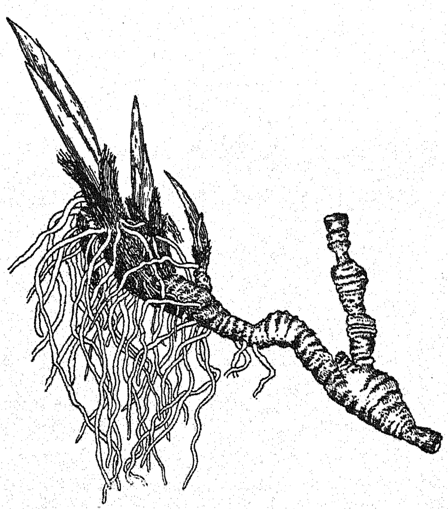


FIG. 34.—Rhizome of Iris, the common Blue Flag. About one-half natural size.

leaf is formed each year and when it breaks off at the end of the season it leaves a round scar, suggesting the seal made by a seal ring (Fig. 33). The rhizome grows by a strong bud at the tip,

while the older parts die off behind, so that the plant gradually moves forward.

In a rhizome like that of the *Iris*, there is a decided narrowing at the close of the season, so that the stem appears jointed. In this case, there are numerous leaf scars each year (Fig. 34). In *Trillium*, and in many others, the rhizome is erect and very slow growing. It dies off at the bottom, while a strong bud at the top continues the growth. During the growing season, rhizomes store up an abundant supply of food, especially starch, which enables them to start promptly and vigorously in the spring.

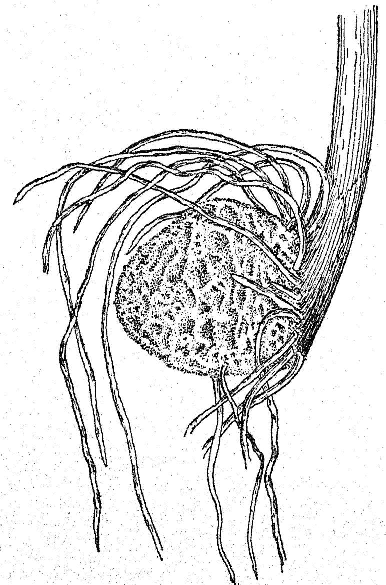


FIG. 35.—Corm of Jack-in-the-Pulpit. Two-thirds natural size.

Corm.—If an underground stem is somewhat thick and more rounded than in *Trillium*, it is called a *corm*. It is

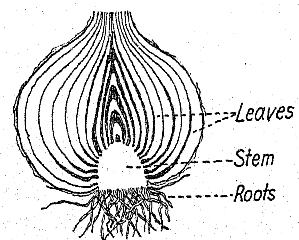


FIG. 36.—Bulb of Onion, one-half natural size.

sometimes called a solid bulb; but a bulb consists principally of leaves, while a corm is nearly all stem. Jack-in-the-Pulpit has a typical corm (Fig. 35).

Bulb.—If the underground stem is short and broad and covered with leaves, it is called a *bulb*. The leaves are sometimes reduced to thickened scales, as in the Lily; but often the leaf bases become thickened, while the upper part of the leaf decays, as in the Onion (Fig. 36).

Sometimes small bulbs are formed in the axils of leaves, as in some Lilies; and sometimes they appear in place of the flower

cluster, as in the Onion. These small bulbs are generally called bulblets. They can be detached and planted like seeds.

Nodes and Internodes.—A stem or branch is made up of a succession of *nodes* and *internodes.* The portion of the stem or branch which bears the leaf, or leaves, is called the *node;* and the leafless portion between two nodes is called the *internode* (Fig. 37).

Plants in which the base of the leaf extends all the way around the stem, as in Corn, have very prominent nodes. In the Bamboo the internode is hollow, but the node extends entirely across the stem, forming a strong partition, so that flower pots are easily made by cutting off the stem just below the node, and then cutting it off again six or eight inches above the node, which makes a good bottom for the pot.

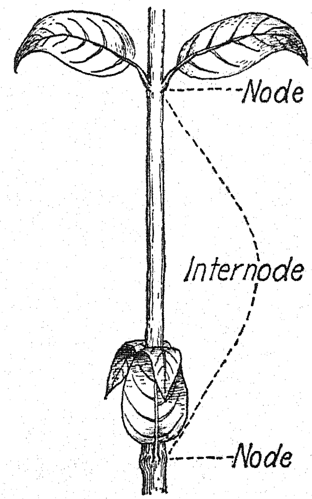


FIG. 37.—Diagram of two nodes, with an internode between them.

Where the leaves are stalked and opposite each other, or where there are three or four or more stalked leaves at a node, the node will be prominent but not so prominent as in Corn. Where the leaves have stalks and are scattered, with only one leaf at a node, the nodes will be inconspicuous.

Buds.—A bud is an undeveloped stem or branch. It consists of a series of nodes and internodes, with leaves in various stages of development; or it may contain young flowers.

The outer part of the bud usually consists of protecting scales, which are modified leaves (Fig. 38). Such scales are often waxy, as in the Cottonwood Poplar; or they are covered with resin, as in the Pines. The edges and, sometimes, the whole inner surface of the scales are hairy, and this is an added protection, especially against changes in temperature. In some cases, as in the Hickory, the outer scales are large and beautifully colored, so that the expanding bud looks like a flower.

When the bud scales fall off in the spring, their scars are easily recognizable, so that the age of a twig can be determined by

counting the number of places from which bud scales have fallen off (Fig. 38*A*). The part between two such groups of bud scale scars, which may consist of several nodes and internodes, was

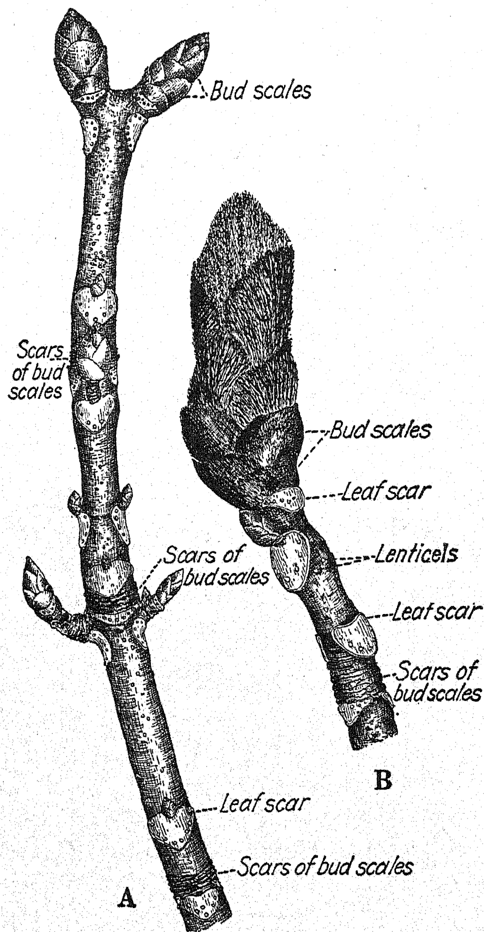


Fig. 38.—Horse Chestnut. *A*, twig with buds in the winter conditions; *B*, spring condition with large bud bursting open. One-half natural size.

contained in a single bud. In Fig. 38 the part between the two big buds at the top and the scars of bud scales below was contained in the bud of the preceding year.

Some buds are naked, with no covering of bud scales. This is the case in annual herbs, in some perennial herbs, in many tropical shrubs and trees, and even in many shrubs and trees where the winters are quite severe. Many shrubs and trees, like the Sumac and Locust, have small buds with no bud scales, but they are covered and protected by the bark.

Buds which are not terminal are formed in the axils of leaves. Consequently, there is a prominent scar just below each bud. The Horse Chestnut and Tree of Heaven (Ailanthus) have very conspicuous leaf scars (Fig. 38).

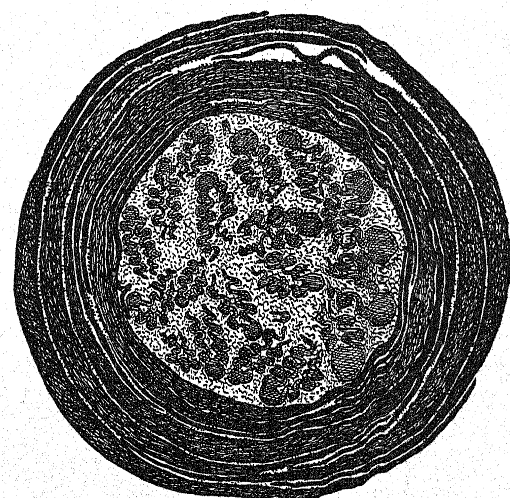


FIG. 39.—Bud of Horse Chestnut: cross-section, showing bud scales, young leaflets and hairs. × 8.

Flower buds, from the outside, generally look just like leaf buds and cannot be distinguished from them; but flower buds often occur in certain fixed positions in certain plants, so that one can make a fair guess as to whether a certain bud contains flowers or only leaves.

Some of the most important structural features of a bud can be seen by cutting a large bud longitudinally through the middle. The Horse Chestnut, Hickory, Cottonwood Poplar, and the Lilac show the internal structures well, but any big bud will do. The nodes and internodes are close together and the young leaves are crowded and packed in various ways. If a large bud is cut

transversely, it is easier to see how the leaves are packed into the small space (Fig. 39). In some buds the leaves are folded like a fan; in some the edges of the leaves are rolled in; and in others the two halves of each leaf are folded together like a closed hinge.

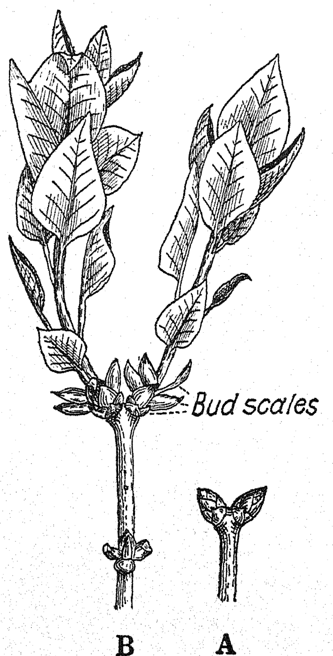


Fig. 40.—Twig of Lilac: *A*, tip of twig with two buds in the winter condition; *B*, condition of the same two buds after a month in the laboratory. A leafy branch has burst through the bud scales of each bud. Two-thirds natural size.

Large buds are likely to have the leaves and other parts in a more advanced stage than small buds. In the Horse Chestnut and other buds of this size, even the principal veins of the leaf may be evident in the winter bud.

When the bud opens in the spring, the internodes elongate rapidly and one can soon see just how many leaves are to be produced. A warm spell in the winter is likely to result in poor foliage the following summer, because the bud scales start to open somewhat, exposing the delicate parts to the cold which is sure to come before genuine spring weather arrives. In the Cottonwood Poplar many leaves may fall almost as soon as they are formed, and in others the foliage is not so luxuriant as in seasons without a mild period in the winter.

It is not necessary to wait until spring to study buds. If small branches a couple of feet long be brought into the laboratory and placed in a gallon jar of water, even in midwinter, the buds soon begin to swell and the whole process of the spreading of bud scales and the unfolding and development of leaves can be watched from day to day. The Horse Chestnut and Hickory are particularly good, but Poplars, Willows, Lilac, and any others will be worth while. Two buds at the top of a twig of Lilac, brought into the laboratory in midwinter, looked as they are

shown in Fig. 40*A*; but within a month the two buds had developed into the two leafy branches shown in *B* of the same figure.

Structure of the Stem.—Some very important features of the structure of the stem can be seen with the naked eye. One can identify many shrubs and trees in the winter condition by noting the general habit of the plant and examining the structure of the young twigs. The principal things to look for are the buds, bud scale scars, the leaf scars, and the *lenticels*.

When the protecting bud scales fall off, they leave characteristic scars which aid in naming the plant, and also enable one to determine the age of a shoot, because there is just one year's growth between any two rings of bud scale scars.

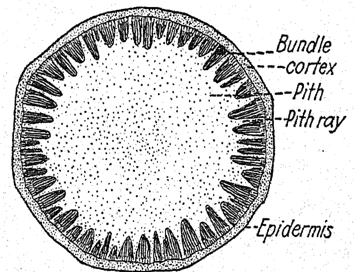


FIG. 41.—Cross-section of stem of common garden Sunflower, showing a large pith surrounded by a zone of wood consisting of many bundles. One-half natural size.

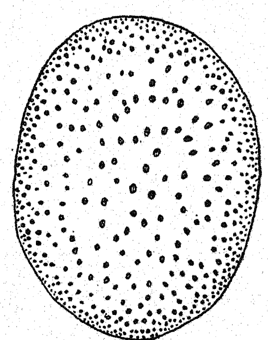


FIG. 42.—Cross-section of Corn stem, showing scattered bundles.

The lenticels are small dots or elongated spots, usually present on young stems and serving to admit air to the living tissues underneath, just as the stomata admit gases to the leaf (Fig. 38). In the Horse Chestnut, *Ailanthus*, and the Elder, they are conspicuous. In many plants they are smaller; but in some, like the Birch, they become very long and narrow horizontally on account of the rapid increase in the diameter of the trunk or branch. The darker streaks in cork are lenticels.

Much of the internal structure of the stem can also be seen without a microscope. If a Sunflower stem and Corn stalk be cut across transversely, it is evident that their structure is very different (Figs. 41 and 42).

In the Sunflower there is a *pith* in the center, surrounded by a zone of *wood*, and outside of the wood is a zone of softer tissue called the *cortex*. The outermost part is the epidermis, which is very thin, usually only one layer of cells in thickness. In a very young stem the woody zone consists of strands, called *bundles*, which are separated from each other by plates of softer tissue,

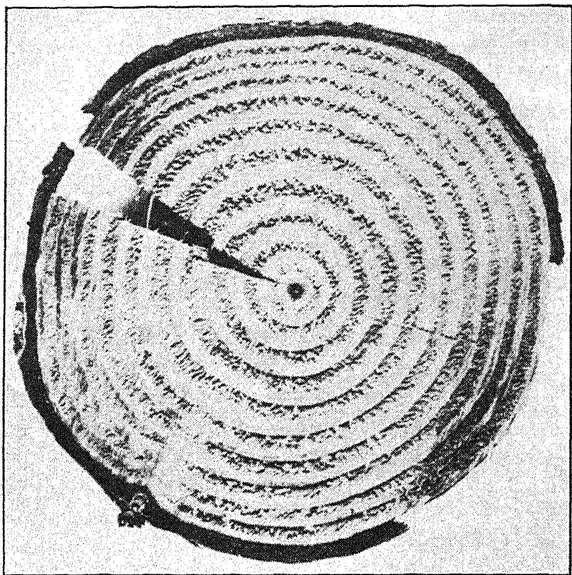


FIG. 43.—Cross-section of the trunk of an 11-year-old Douglas Fir. The darker part of the annual ring is the spring wood and the lighter part is the autumn wood. One-half natural size.

called *pith rays*, or *medullary rays*. If the section is made farther down, the bundles will be tougher and more numerous, and the pith rays will be thinner.

A similar view of a Corn stalk shows a large number of bundles scattered through a softer tissue; but the bundles are not grouped together into a woody zone with a pith in the center and a cortex outside.

The stems of nearly all herbs, shrubs, and trees show one of these two types of structure. It is interesting to note that most plants with netted veined leaves have a pith, zone of wood, and a

cortex, like the Sunflower; while nearly all plants with parallel veined leaves have the Corn-stalk type of structure.

In perennial plants with a pith, zone of wood, and a cortex, a new zone of wood is formed every year, and the successive zones are usually conspicuous. These zones are called *annual rings*, and the age of a plant can be determined by counting the number of its annual rings (Fig. 43).

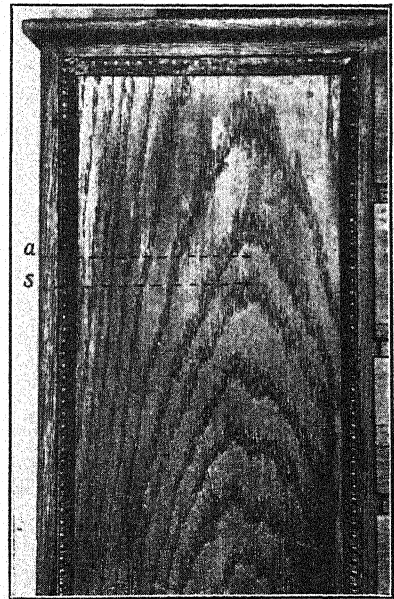


FIG. 44.—Grain of Oak wood. The darker part of the grain is the spring wood of the annual ring, and the lighter part is the autumn wood.

In climates with a well-marked summer and winter, the age of a tree can be determined with almost perfect certainty by counting the rings; and the age is almost as easily determined in warmer climates with a well-marked dry and rainy season. In tropical climates, however, some trees form several rings in a year. Even in temperate climates when a peach or an apple tree flowers in the autumn, there is likely to be an extra ring in that year; but the extra ring is weaker and is not likely to deceive a botanist.

The part of the ring formed in the autumn is harder and takes a finer polish than that formed in the spring, and this is the cause of the beautiful grain of wood as we see it in our furniture (Fig. 44). In the Oak the lighter colored smoother part is the autumn portion of the ring; and the darker part, not nearly so smooth, was formed in the spring.

The elegant symmetrical patterns seen in pianos, victrolas, and in display windows are obtained by making half of the panel from one board and the other half from the board which was sawed off next to it. If any board with good grain is sawed lengthwise so as to make two boards, and the edges of these are placed

together, as if you had opened a book, you will get a symmetrical figure. In expensive lumber, like Mahogany, the log is cut into very thin boards and the boards are kept in the same order in which they came off, so that any two successive boards will make a symmetrical figure.

In looking at the stump of a tree, it is evident that the outer part of the wood, a zone usually about an inch wide, is lighter in color than the rest of the wood. The outer zone is called the *sap wood;* and the darker part, between the sap wood and the pith, is the *heart wood.* The difference in color is most marked in trees like the Black Walnut, where the white sap wood contrasts sharply with the dark heart wood. The sap wood is comparatively soft and is not worth much for lumber.

Outside the woody zone is the *bark.* In most shrubs and in some trees it is smooth; but in some shrubs and in most trees the growth of the woody cylinder causes the bark to crack in various ways which are so characteristic that many trees can be recognized by their bark. The Hickory, with its shaggy bark, the Sycamore, with its bark scaling off in broad plates, the Eucalyptus, with bark scaling off in long strips, and the Juniper, with its stringy bark, are as well marked by their bark as by their leaves. As the old bark cracks and weathers off, new bark forms to take its place.

Some kinds of bark, like Cinnamon and Sassafras, are used on the table; Birch bark is used in making light canoes; the bark of the Cork Oak is used in making corks, and many kinds of bark are used in making drugs.

Microscopic Structure.—The microscopic structure of the stem is very complicated. Like the leaf, it is made up of cells; in fact, the whole plant is made up of cells, just as a house may be made up of bricks. The cells, when young, are more or less cubical in form, but they soon assume various shapes. In the pith the cells become somewhat rounded but otherwise retain something of their original form. In the cortex some of the cells are not very much modified, but others are greatly changed.

The greatest change from the original condition of the cell occurs in the woody zone. Many cells become greatly elongated and the transverse partitions between neighboring cells break down, so that long tubes are formed. In the Oak these tubes, or

vessels, are easily visible to the naked eye. In furniture finished as "golden oak" or "English oak," they appear as dark lines, often several inches in length. Under the microscope their walls are covered with numerous pits.

The first wood formed in any stem has vessels marked with rings and various spirals, but later wood has other markings, usually pits. It is easy to get a good view of the spirals. Cut a piece, about an inch long, from a young Sunflower stem or the stem of the Castor Oil plant, and from this cut longitudinally a piece like a thick piece of pie. At the middle of the long piece, cut into the pith almost to the woody zone and, from the opposite side, cut almost down to the pith. Then break gently and pull apart and the spirals will stretch out between the two pieces. A piece of a leaf, at one of the large veins, will show the spirals just as well (Fig. 45).

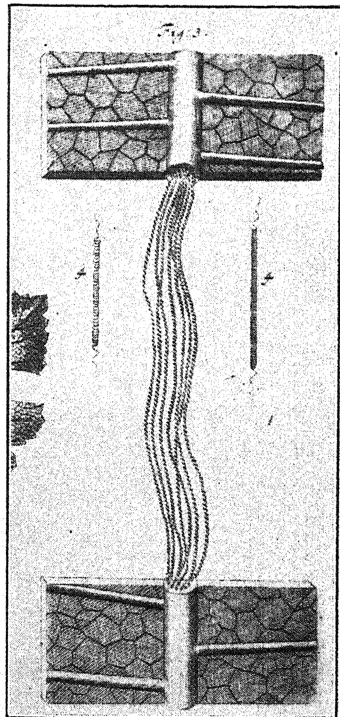


FIG. 45.—Spiral vessels in a Vine leaf. (*Copied from Nehimiah Grew's Anatomy of Plants, published in* 1682.)

In any season the wood formed in the spring consists of large cells and the size of the cells then diminishes, becoming decidedly smaller in the summer, while during the autumn and winter there is a resting period with no cell formation. Consequently, in a perennial there is a repeated alternation of larger and smaller cells, as one looks along a radius from the pith to the cortex (Fig. 46). To the naked eye the denser autumn wood, abutting on the less dense spring wood, gives the impression of a ring, and, since one is formed each year, we call it an annual ring.

The pith rays are often only one cell thick and their walls are thin; but in some trees, like the Oak, the rays are much broader

and their cells become so thick and hard that they form a prominent feature of the grain.

Physiology of the Stem.—The stem supports the branches, with their leaves, and conducts liquid materials from one part of the plant to another.

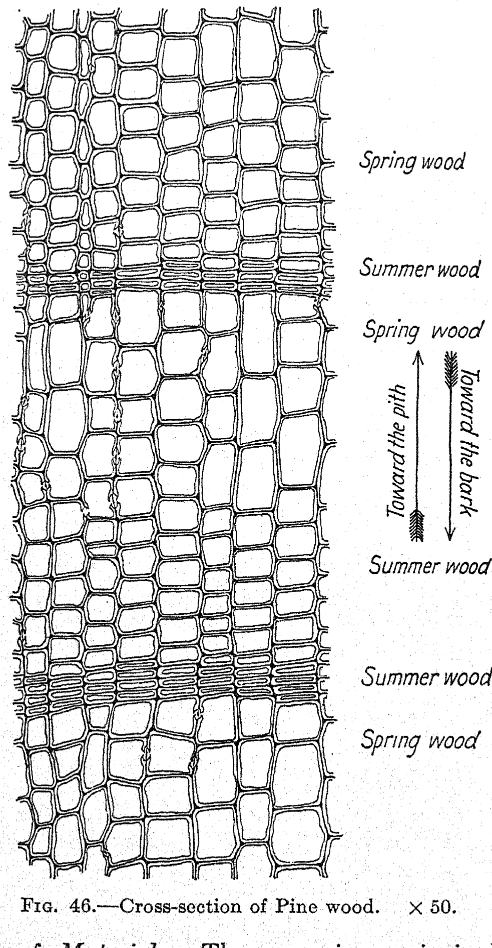


FIG. 46.—Cross-section of Pine wood. × 50.

Movement of Materials.—The sap rises principally in the bundles, as can be seen easily in plants like Coleus and the Touch-me-not. Take about a foot of the top of the plant, cut the lower end of the stem off *under water* with a very sharp

knife, and into the water put a little of some harmless dye, like Eosin. In a few minutes the water with the dye will be rising and, in 10 or 20 minutes, may reach a considerable height. In a translucent stem, like that of the Touch-me-not, the liquid can be seen from the outside; but in most cases it will be necessary to cut the stem off a few inches above the water and look at the cut surface. It will be seen that the bundles are stained with the dye, while the rest of the tissues may not be at all colored. Try the same experiment with a potato. Cut off about one inch from the bottom of a potato (for a potato has an apex and a base) and place the cut end in the colored solution. In half an hour make another cut an inch above the first one. It will be seen that the liquid has risen in the bundles, which are near the outside and more or less scattered but still arranged in a ring.

Another experiment, which has been repeated for nearly two hundred years, will show that the principal upward movement of sap is in the wood. From a Willow twig, about as large around as a lead pencil, remove about one vertical inch of bark. The twig may be left on the tree or, if brought into the laboratory, may be placed in a can of water. In placing any plant in water in this way, it is better to cut the bottom end off under water, because even an instant of drying is bad, and air, getting into tubes of the wood, impedes the movement of liquids. The leaves will keep fresh for several days, because they get about the same amount of water as they would if the plant had not been girdled. A similar twig cut off and not placed in water soon loses its leaves.

By taking extreme care, a vertical quarter of an inch of the wood of such a twig can be removed without much damage to the bark. The leaves soon fall, and fall at about the same time whether the twig is placed in a can of water or in a dry can. This experiment shows that practically no liquid rises to the leaves through the bark.

In a tree most of the upward movement is in the sap wood. If a tree be girdled so that the cut extends through the sap wood, it soon dies. In making maple sugar, a hole ½ inch or less in diameter is bored about 3 feet from the ground and about half way through the sap wood. A spout is driven into the hole and a pail underneath catches the sweet sap. As much as 3 gallons

may drip from a single spout in 24 hours. If the hole is bored too deep, so that it reaches the heart wood, and the spout is driven through to the heart wood, scarcely any sap is secured. The flow of rubber and turpentine is also largely through the sap wood.

Those experiments do not mean, however, that there is no movement of materials in the bark. If the twig from which a girdle of bark has been removed be kept a couple of weeks, with the water changed occasionally and the lower end cut off, *under water*, every few days, it will be seen that there has been a downward movement of material through the bark. At the upper end of the girdle there will be some increase in diameter and roots are likely to appear (Fig. 47). Roots do not originate in the wood but in the bark, and the materials for the production of the roots and the increase in diameter came down from the leaves through the bark.

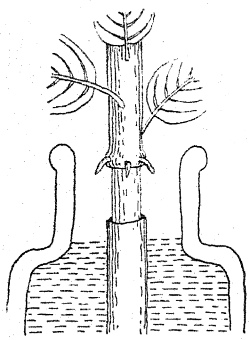


FIG. 47.—Experiment showing that there is a downward movement of material in the bark. Just above the water in the bottle, a ring of bark has been removed. Three roots have broken through the bark.

This is what has been going on: sap, with various substances in solution, has been carried up by the stem to the leaves, where crude materials have been manufactured into usable foods, which have then been conveyed downward through the bark and have supplied the material for the swelling and the roots.

Many experiments along this line prove that there is an upward movement of materials through the wood and a downward movement through the bark. Much of the material brought down is not expended in growth but is stored in the bark, as in Cinnamon, Sassafras, and in the numerous cases in which bark is valuable for the manufacture of drugs.

Heliotropism.—Plants are profoundly influenced by light. The stem naturally grows erect, but, if the light is uneven, the younger parts of the plant will turn toward the light. When the light comes from a window, house plants bend toward the light; so that the plants must be turned every few days to keep them symmetrical. This turning toward the light is called *heliotropism*. The *helio* means sun, and the *trop* means a turning.

If seeds are germinated in a small dish of wet sand and placed near a window, the young plants will soon bend toward the light (Fig. 48). If the dish be placed in a dark box, with a hole about an inch in diameter to admit the light, the turning is even more marked. For this experiment, small seeds, like those of Mustard, Radish, and Flax, can be germinated on a sponge placed in a dish of water.

Geotropism.—Gravity is also a strong factor in the growth of plants. Stems naturally grow straight up and roots straight down (Fig. 49). This response of plants to

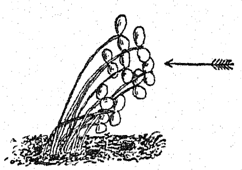


FIG. 48.

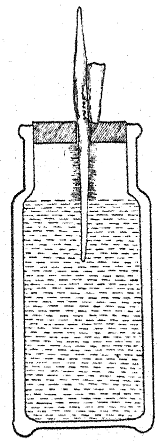


FIG. 49.

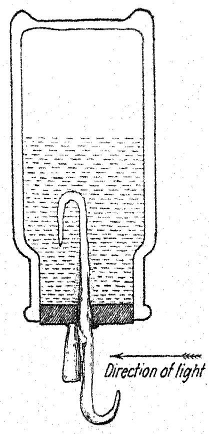


FIG. 50.

FIG. 48.—Seedlings of Mustard, showing heliotropism. One-half natural size.

FIG. 49.—Seedling of Corn, showing stem growing straight up (negative geotropism), and root growing straight down (positive geotropism). The part of the root above the water in the bottle has numerous root hairs.

FIG. 50.—The seedling of Corn shown in Fig. 50, after the bottle had been inverted for a couple of days. Positive geotropism has made the root bend over and grow down again, and negative heliotropism has made it turn away from the light. Negative geotropism has made the stem turn up and positive heliotropism has made it turn toward the light.

gravity is called *geotropism,* the *geo-* meaning earth and the *-trop-* a turning.

Take a rapidly growing twig of Willow, about one-eight of an inch in diameter and six inches long, and a wide-mouthed bottle holding about half a pint of water. Put the twig through a hole in the cork and make everything water tight with chewing gum or paraffin. Then turn the bottle upside down. In a few days the tip of the stem will begin to turn up and soon will become erect. The turning up is due to gravity, and this turning away from the earth is called *negative* geotropism.

If a seedling of Corn, Bean, or other easily available plant be used instead of the twig, another feature can be shown at the same time; for the stem will turn up as before, and the root will curve over and bend down, giving an example of *positive* geotropism (Fig. 50).

Still more can be learned from this experiment if the plant is kept in a dark box, with light admitted through a hole about an inch in diameter; for the stem will not only turn up, but it will also turn toward the light; while the root will not only turn down, but it will also turn away from the light. In the turning down of the root and turning up of the stem, there are illustrations of positive and negative geotropism; while, in turning toward the light, the stem shows positive heliotropism; and the root, in turning away from the light, shows negative heliotropism.

Uses of Stems.—Of course, the stem, or trunk of a tree, is used for lumber. Wood has always been the universal building material; but other uses are innumerable; you could think of a hundred in a few minutes: railroad ties and telegraph poles; barrels and tubs; tables and chairs; the piano may be made of Mahogany; the chiffonier of Bird's Eye Maple; the hope chest and lead pencil are made of Red Cedar; the wood of the Apple tree makes good chisel handles and chessmen; and the handle of your pocketknife may be made of Hickory bark.

In the days when fine trees were abundant, Lincoln split Oak logs into rails; and 50 years ago, in the Western Reserve, Black Walnut was used for rail fences because it was so durable and easy to split; but, less than 20 years later, when Walnut was becoming scarce, the fences were replaced by Oak and the Walnut rails were turned into table legs and smaller articles. In the West, they still have lumber enough for rail fences.

For fuel, wood is becoming a luxury in most parts of the country; but in the West you still see the big, picturesque fireplaces with their blazing logs. In most of the rest of the country the days are past when everyone knew by the crackle or the odor whether the log was Hickory, Maple, Beech, or Pine.

Where forests are abundant, lumber companies are likely to be reckless in their methods. A giant Kauri tree, 8 or 10 feet in diameter, is allowed to thunder down the mountain side like an

avalanche, destroying a dozen trees 2 or 3 feet in diameter, besides smaller ones, before it reaches the bottom. In our own country White Pine has become so scarce that it has ceased to be the dominant wood for general building. The Redwoods of Oregon and California were becoming so depleted that national preserves became necessary and a society for preserving Redwoods was organized and is still active. In Europe lumbering has ceased to be so wasteful and reforesting has become an art; and, even in the United States, tree planting is encouraged and the government is making some progress in reforestation. Every up-to-date school observes Arbor Day.

Immense quantities of wood are used in making paper. The Chicago Tribune uses an average of 255 tons of paper a day. Between 400 and 450 acres must be stripped of their trees to furnish one week's issue of this paper. Most of the paper is made from the trunks and branches of trees, especially cone-bearing trees.

On our western prairies trees have been planted for windbreaks, and they not only serve this useful purpose but also afford shade and relieve the monotony of the landscape.

In parks and on lawns the decorative value of shrubs and trees is evident. In selecting trees for parks, streets, and lawns, one should bear in mind the character of the soil, whether the plant is to be on a hilltop, on a hillside, or in a low damp place. If plants are to be transplanted, one can note their natural surroundings and try to imitate them. In most places the landscape gardener of a successful park is a good person to consult when buying plants for a lawn; but along our Pacific Coast it looks as if anything one's fancy might lead him to select will grow and reach perfection.

For decorative purposes vines should not be overlooked. Morning Glories will relieve even the rear porches of city flat buildings; while the ugly brick garage in the backyard may cease to be an eyesore if covered with Ivy.

Diseases of the Stem.—The diseases of shrubs and trees are receiving more and more attention, and no class of botanists has a larger membership than the plant pathologists, or plant doctors. Many diseases are due to insects, like lice, moths, and bugs; some are due to worms; but more are due to Fungi, that low

group of plants which includes the Mushrooms, Toadstools, Bracket Fungi, and thousands of others.

When the Mushrooms or Toadstools appear at the base of the tree, that means that the tree is already badly diseased, for the Mushroom is only the fruit of the fungus; the vegetative part has been growing inside for a long time, ruining it for lumber and weakening it so that it is in great danger from wind. When the Bracket Fungus appears, the trunk, up to that level, is diseased and weakened.

Pathologists can tell, from the kind of fungus and its position on the trees, about how bad the damage is and how much of the timber is ruined. In the magazines, like the *National Geographic*, you see advertisements of pathologists who call themselves "tree surgeons." In parks and cities, where trees are scarce and valuable, the tree surgeon often saves trees which otherwise would die in a short time. They cut out the diseased portions, sterilize, and then fill in with cement, as a dentist fills a tooth.

Some diseases develop after the timber is seasoned and has been built into the house. Such diseases are insidious and, generally, when detected, the only remedy is to replace the diseased timbers.

Diseases of the heart wood often cause a tree to become hollow. A fallen California Big Tree in the Calaveras Grove has such a large hollow in the trunk that two men can walk abreast through a piece nearly a hundred feet long. An expert in diseases of trees could probably have estimated, fairly well, the diameter and height of the hollow before the tree fell. It is evident that timber companies, in estimating the value of a tract of forest land, need the services of an expert in the diseases of trees.

CHAPTER III

THE ROOT

Roots grow down into the ground and, since they are out of sight, most people know much less about them than they do about stems; but, without the root, the stem would have nothing to conduct up to the leaves, and the leaves would have little crude material to manufacture into usable food. Consequently, the root, although out of sight, is very essential in the life of the plant.

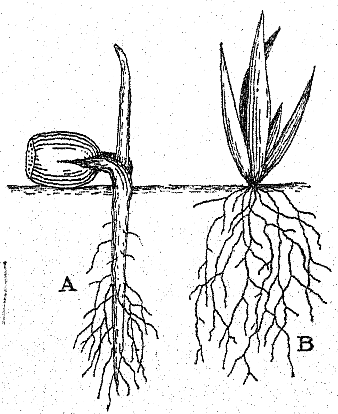


FIG. 51.—Seedlings: *A*, Oak, showing tap root; *B*, Grass, showing fibrous roots.

Stem and root are opposites in many ways. The stem has leaves, nodes, and internodes; it grows in length by the elongation of its internodes. The root has no leaves, and neither nodes nor internodes, and it lengthens at the tip.

The stem turns up toward the light, while the root grows down into the dark (Fig. 51). These opposite tendencies, established even before the young plant breaks out from the seed, continue throughout its entire life. The tendency of the stem to grow up and the root to grow down is so strong that, if a seed be planted with the stem end down and the root end up, the stem will curve and grow straight up, while the root will curve in the opposite direction and grow straight down. We have already used the terms heliotropism and geotropism, but it must always be remembered that the long names merely describe the behavior; they do not account for it.

Besides the tendency to grow down and to grow away from the light, there is such a strong tendency to grow toward water

that the position of water may cause a root to bend away from its normal direction and even cause it to turn toward the light.

The tip of a root is covered by a *root cap,* which protects the delicate growing point as it forces its way down through the soil. The cap keeps scaling off but is just as constantly renewed by the growing point which it protects.

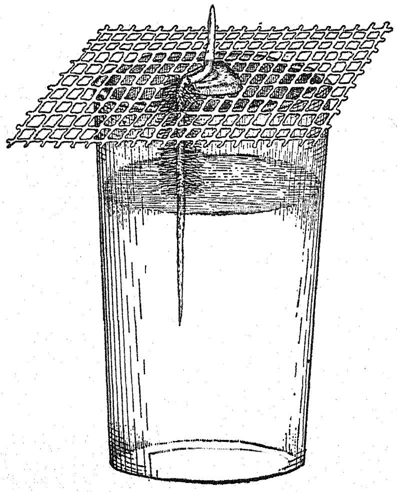


FIG. 52.—Grain of Corn germinating. The part of the root above water has numerous root hairs, but the part below has none at all.

A short distance back from the root tip is a region which produces numerous *root hairs.* When a Mustard seed is planted, a dense growth of root hairs will be found as soon as the plant appears above ground. Most young plants will show a growth of root hairs before the plant is half an inch above ground. If seeds of Mustard, Flax, or Wheat are germinated on moist filter paper in a covered glass dish, there will be a great number of root hairs; but if the young root is in water there may be no hairs at all.

When Corn is germinated on a coarse wire screen placed over a tumbler three-fourths full of water and covered by a glass jar to keep the air moist, the part of the young root between the screen and the water will have hundreds of root hairs, but the part which gets down into the water will be perfectly smooth (Fig. 52).

The root hairs anchor the young plant and absorb water with various substances in solution. These substances are then passed on from the root hairs, through the cortex to the woody part of the root, and up to the stem and leaves.

Whether the food materials are naturally present in the soil or have been added in the form of fertilizers, they can enter only in the liquid condition. Much enters by the root hairs; but, where there are no root hairs, the mode of entrance is the same. The

cell walls are membranes and the water, with various things in solution, passes through the cell wall of the root hair into the cell. That materials may pass through a membrane which appears to be water tight is shown by a simple experiment. Pour celloidin (collodion) into a small drinking glass—about one and one-half inches in diameter at the top and a couple of inches deep—and then pour nearly all of it back into the bottle. After it has hardened for a few minutes, peel it out carefully, so that you will have a thin membrane the size and shape of the glass. Fill it with water. The water does not soak through; the membrane holds water as well as the glass. Pour out the water and pour in a weak sugar solution, a teaspoonful to a teacupful of water. Place the membrane cup in a small dish of pure water, tinged with a slight trace of red ink. Within an hour, there will be a tinge of red inside the membrane cup, showing that the solution has passed through the membrane. Instead of the ink, a very dilute solution of calcium phosphate, potassium nitrate, or ferric chloride, which are commonly present in the soil moisture or in fertilizers, may be used, and chemical tests of the liquid in the membrane cup will soon show that these inorganic substances have passed through the membrane. If the solution in the cup is too strong, the movement will be from the cup into the liquid outside; but, in nature, minerals in solution in soil moisture are present in extremely small quantities. Materials move from the root hair into the next cell and on to the conducting strands in much the same way.

Once inside the conducting strands, evaporation of water from the leaves exerts a strong pull which is an important factor in the upward movement of liquids. Capillary action is another cause of the upward movement. Take a glass tube about 4 inches in length and three-sixteenths inch in diameter and heat it in the middle until it begins to soften; then pull it apart rather quickly. In this way you can get a small tube about one-thirty-second inch in diameter and a couple of feet in length. When it cools, break off one end and insert it in weak red ink. By *capillarity* the ink may rise the whole length of the small tube. Root pressure due to absorption by the root is another factor in the upward movement of liquids. Other factors are described by physiologists, and there may be still others not yet

discovered; but under the influence of the factors mentioned, and perhaps others not yet known, the water with various substances in solution reaches the leaves and other green parts of the plant where the inorganic substances are converted into usable foods.

The processes are not nearly so simple as the description, for in addition to the cell wall, there is living protoplasm. The membrane cup simulates the cell wall but not the living protoplasm.

The first root of a young plant is called the *primary root;* branches from it are called *secondary roots;* but the term, secondary root, is also applied to any side branch of any root. Other roots may arise from the stem or even from the leaves. These are called *adventitious roots.*

If the first root grows vigorously, putting out smaller side roots, it is called a *tap root;* but if the first root is weak, or disorganizes completely, there will be a number of roots of about the same diameter, and they are called *fibrous roots* (Fig. 51).

Tap Roots.—The Oak furnishes a good example of the tap root. When the acorn germinates, the strong primary root grows down and persists throughout the life of the tree (Fig. 51).

In the Cycads, a rather unfamiliar tropical and subtropical group, represented in most greenhouses by the Japanese Sago Palm, the plant has fresh green leaves, even when growing in very dry places, because the long tap root extends down through the dry surface soil into the damp soil far below. A plant with a stem a foot high may have a root 10 feet long (Fig. 53).

In some seedlings, like that of the Honey Locust, the strong tap root reaches a great depth, but produces an immense number of secondary roots which extend horizontally and do most of the nutritive work; while in seedlings of wheat, there are several roots more or less alike (Fig. 54).

Many perennial herbs have such strong deep tap roots that it is almost impossible to pull them up. An herb 2 feet high may have a tap root 20 or even 30 feet deep.

In many trees, however, the primary tap root is weak or short lived. In such cases, widely spreading secondary roots extend more or less horizontally and both anchor the tree and perform all other functions of roots. When such a tree, 50 or 75 feet in

FIG. 53.—Extremely long root of a cycad (*Dioon spinulosum*).

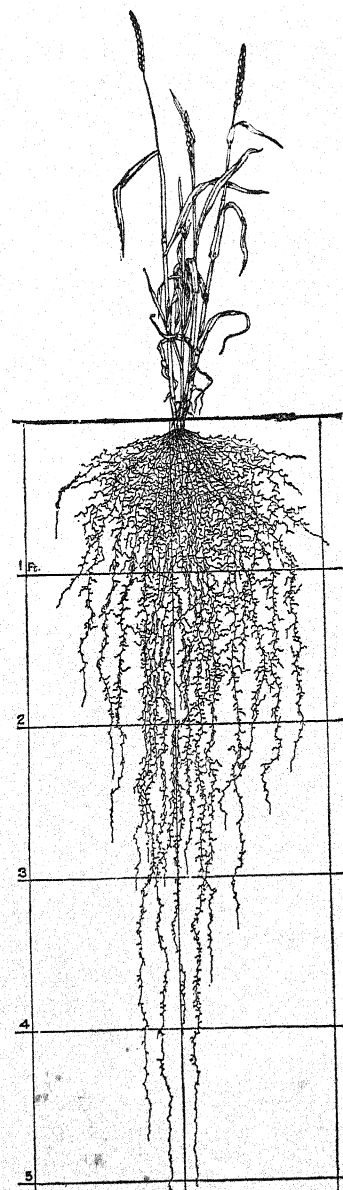


FIG. 54.—Wheat at time of blossoming. (*After Weaver.*)

height, is overturned by the wind, the layer of soil torn up with it may not be more than 2 feet thick.

In many garden plants, like the Cabbage, the primary tap root is usually broken off in transplanting and numerous secondary roots take its place, so that the root system becomes fibrous. In plants which normally have tap roots, a fibrous root system usually develops if the primary tap root is cut off.

Fleshy Roots.—In shrubs, trees, and in many herbs the root becomes as hard and woody as the stem itself; but in many herbs

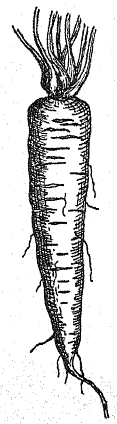


Fig. 55.—Conical root of Carrot.

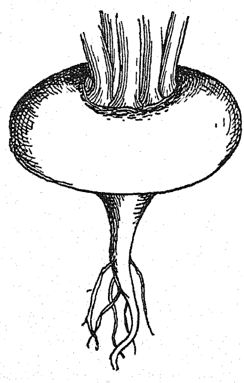


Fig. 56.—Turnip shaped (napiform) root of Turnip.

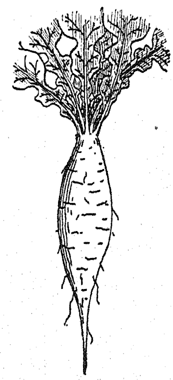


Fig. 57.—Spindle shaped (fusiform) root of Radish.

the root becomes fleshy from the storage of starch and water, or sugar and water, together with smaller amounts of various other substances which add characteristic flavors.

Fleshy roots are common in dry regions, where they enable the plant to survive through long periods of drought. For the protection of the plant, this is better than storage in parts aboveground, because the root escapes most animals, while a moist fleshy morsel above ground in a dry season would be eaten.

Examples of fleshy tap roots are found in our most familiar garden vegetables, the shapes of which are so characteristic that they have suggested names for the principal types of fleshy roots.

If the root is largest at the top and tapers evenly to a point, as in the Carrot, it is *carrot shaped* or *conical* (Fig. 55); if it is

largest in the middle and rounds off rather suddenly above and below, as in the Turnip, it is *turnip shaped* or *napiform* (Fig. 56); if it is largest in the middle and tapers gradually to the top and bottom, as in the Radish, it is *radish shaped* or *fusiform* (Fig. 57). While these are typical shapes, some varieties of Turnips are fusiform and some Radishes, like the little red ones so common on the table, are napiform.

Even in the city, fleshy roots are familiar in the grocery; and outside the city in meadows and woodlands, many flowers, even the smallest, show some type or other of fleshy root.

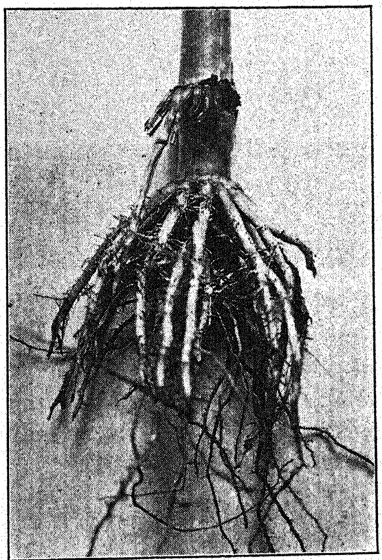


FIG. 58.—Adventitious roots of Corn. All roots coming from the stem above ground are adventitious.

The fleshy condition, while not so common in secondary roots, is familiar in cases like the Dahlia and the Sweet Potato. In the Sweet Potato the storage is at various places so that, at first glance, it looks as if an underground stem might be thickened, as in the Irish Potato.

Fibrous Roots.—If the primary root is weak or disorganizes early, there will be numerous secondary roots of more or less the same size. They are called *fibrous roots;* but the term is applied to any roots, both primary and secondary, when they are numerous and slender (Fig. 51*B*).

If Corn, Wheat, or Oats be dug up a month after planting and the soil be washed away very carefully, good views of the extensive fibrous root system can be secured. But it is not necessary to make plantings except in midwinter in colder parts of the country, for any annual grasses and weeds may be dug up and washed.

Adventitious Roots.—Roots which arise from the stem or the leaf are called *adventitious roots.* Prostrate stems and rhizomes

will always furnish illustrations (Fig. 33); but adventitious roots are very common and rather familiar because so many of them are above ground where they are easily seen.

Corn always furnishes a good example of adventitious roots. They come out from the stem at the first two or three nodes aboveground and, occasionally, from still higher nodes, curve over, enter the soil, and do the work of ordinary roots (Fig. 58).

Fig. 59.—Large adventitious roots of Screw Pine.

Roots of this kind, but on a big scale, are found in the Screw Pine, where they may reach a diameter of a couple of inches and a length of several feet (Fig. 59). In small potted specimens these

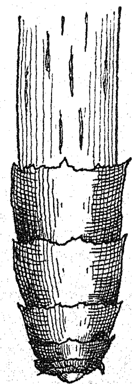


Fig. 60.—Adventitious root of Screw Pine, showing prominent root cap. Natural size.

roots are often as large as a lead pencil and have root caps an inch long (Fig. 60).

Monstera deliciosa, a tropical climber whose big leaves develop large holes, is rather common in the greenhouses of city parks. It has large adventitious roots by which it clings to Palms or other supporting trees. The root caps are highly developed even before the roots reach the soil.

In the Mangrove, roots from the stem branch before they reach the ground, forming such a dense tangle that any progress

in a mangrove swamp, like those of southern Florida, is slow and tedious.

The largest of all adventitious roots are those of the Banyan. They grow down from the horizontal branches and, when they reach the ground, take a firm hold and become trunks which reach a diameter of several feet and behave like ordinary trunks, putting out branches from which more roots develop, so that the original tree becomes a grove (Fig. 28).

Orchids often have adventitious roots. In the tropics hundreds of kinds of orchids grow high up on the branches of trees. There is some decaying matter in such places and ordinary roots extend into it; but larger roots from the stem hang down a short distance and absorb moisture and gases from the air.

The Curtain Vine, often seen in park greenhouses, makes a spectacular display of adventitious roots, hundreds of them about $\frac{1}{16}$ inch in diameter hanging straight down 20 or 30 feet, so that they look like a screen.

In the preceding cases the adventitious roots are formed naturally and are a constant feature in the life of the plant; but such roots can often be forced to develop where they do not occur normally.

The India Rubber plant, so common in the house and in window boxes, is propagated commercially by taking advantage of its strong tendency to produce roots from the stem. A foot, or somewhat less, from the tip of a stem or branch, make a cut almost to the middle and extending upward about two inches. Keep the slit open by crowding in some wet Peat Moss: then tie a big handful of the moss around the cut place and keep it moist. When the roots, which will develop from the cut place, are one or two inches long, which may be in a month or six weeks, cut the branch off, just below the moss, and place it in a pot or a window box. The moss should not be removed. Simply pack the soil about it and an inch deep on top of it and the young plant should grow all right. By studying Fig. 61, any student can do this operation.

If a rubber plant growing in the house becomes too tall, the top may be treated in this way. When the top is cut off, branches appear at the sides, and the plant becomes broad instead of tall and slender. The new side branches can then be treated in

the same way and will yield plenty of young plants for window boxes.

A Willow twig placed in a jar of water or moist soil soon develops roots. In this case it is interesting to note that the twig will grow into a new tree, whether the tip or the base is

FIG. 61.—Adventitious roots formed in propagating the Rubber Plant. The upward cut is shown at *A*; the cut portion, bound up with Peat Moss, at *B*; and at *C*, roots developing from the cut.

down; so that the tip of the twig may become the root end of the new tree. The growth of roots in the Willow is so vigorous and so rapid that when they get through some crack into a water pipe or sewer pipe they may completely fill it and make a great deal of trouble.

Begonias are usually propagated by cutting a vigorous leaf into several pieces and placing the pieces edgewise into moist sand or soil. Roots will develop from the part of the leaf

underground while buds develop above, and so a new plant is started.

Duration of Roots.—Like stems, roots may be classed as *annual*, *biennial*, or *perennial*.

Naturally, an annual plant will have only an annual root; a biennial plant, a biennial root; and a perennial will have a perennial root; but many perennial rhizomes have annual roots.

A plant, like the Tomato, which is an annual in Ohio, becomes a perennial in Mexico and California, growing to a large size and constantly producing tomatoes for several years.

Winter Wheat, planted in the autumn, has two periods of growth, one in the autumn, with a cessation of growth during the winter and a resumption of growth in the spring, with the production of seed and death of the plant the second autumn. Consequently, the plant may be classed as a biennial, although some prefer to call it a winter annual. If the same seed had been planted in the spring, it would have produced seed the same season and would be classed as an annual. Many plants behave in this way. On the other hand, some plants, like the Castor Bean, which are perennial in a warm climate, become annuals where the winters are severe.

Branching of the Root.—Branches come from the outer part of the woody region of both primary and secondary roots. The young branch forces its way through the bark, fracturing it as it emerges. This is easily seen in the Windsor Bean. If the beans are soaked in water for a day and then planted in moist sawdust or soil, the secondary roots will be large enough to show this feature within a week.

Structure of the Root.—The structure of the root, as seen with the naked eye, differs somewhat from that of the stem.

Most roots have no pith, the woody part being solid to the center. Outside the woody part is the bark, which cracks and wears away and is renewed, as in the stem; but it does not become so deeply furrowed as in many stems and does not scale off in such large pieces as in the Hickory, Sycamore, Eucalyptus, and Grape Vine.

The part of the bark outside the region where renewal is taking place does not permit the passage of water. This is one reason why bark dries up and scales off.

In perennial roots there are annual rings as in perennial stems, so that the age of a root can be determined by counting the number of its annual rings.

Microscopic Structure of the Root.—The structural elements of the root are very much like those of the stem, but their arrangement is different. In the young stem the first wood to develop is on the inside, next the pith; while in the root the first wood is the outermost part of the woody region. In both cases the first wood is made up of cells with spiral markings on their walls.

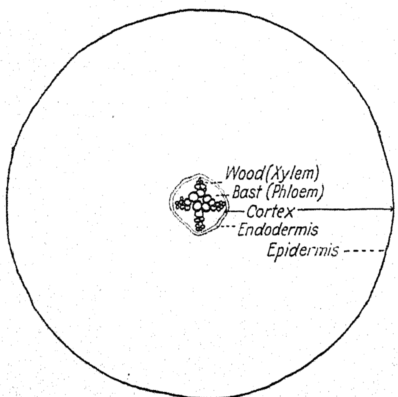


FIG. 62.—Cross-section of root of Buttercup, with only four xylem points. × 50.

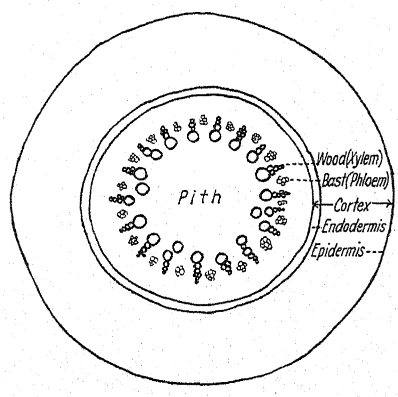


FIG. 63.—Cross-section of root of Smilax with many xylem points. × 50.

The shape of the woody region, as it appears in a transverse section of a young root, is radial, the woody tissue, which is called *xylem*, projecting like the spokes of a wheel with the softer tissue between. In the Dicotyls which, as we have already seen, have netted veined leaves and stems with a pith and a zone of wood surrounded by a cortex, there are only a few of these projections, usually three, four, or five; while in the Monocotyls, which, as we have also seen, have parallel veined leaves and scattered bundles, there are many of the projections, usually more than five and often a dozen or even more.

A comparison of transverse sections of the roots of the Buttercup, which is a Dicotyl, and *Smilax*, a Monocotyl, will illustrate the difference (Figs. 62, 63). Other Dicotyls which show this feature particularly well are the Elder and the Windsor Bean.

Other favorable Monocotyls are the common Onion and the Blue Flag.

The small cells at the tips of the projections are the first cells of the woody tissue to become hard, and, on this account, they are called *protoxylem* (first wood). In longitudinal view they show the spiral type of thickening on their walls. The rest of the cells of the wood have pits or reticulate markings.

The soft tissue between the projections is called *phloem*. It is in this tissue, in both roots and stems, that much of the downward movement of elaborated food material takes place.

On the whole, the root is more uniform in structure than the stem, probably because in its usual position its surroundings are more uniform.

In summing up the functions of root, stem, and leaf, it can be said that the root—besides anchoring the plant—absorbs water with various substances in solution and passes them on to the stem, which conducts them up to the leaf. The crude materials thus brought to the leaf, together with carbon dioxide and other materials which the leaf gets from the air, are converted, by the green cells of the leaf, into usable foods, some of which are used by the leaf itself, while the rest are conducted downward and distributed to all living parts of the plant.

CHAPTER IV

THE FLOWER

The flower is beautiful, and when one makes a scientific study of it he not only gains a deeper appreciation of its beauty, but he also finds endless variations and modifications of structures which form the basis for theories of development and of relationships among plants.

While we all think we know a flower when we see one, no definition has ever been made which satisfies those who have made any real scientific study of the subject. Of course, a dictionary will define anything; but an advanced university textbook makes the statement that any strict definition of the flower is impossible. So, if we let the Rose, the Lily, and the Morning Glory stand as our idea of a flower, and then try to enlarge our view enough to include the Jack-in-the-pulpit and the flowers of the Willow catkin, we shall not need any definition.

The flower is of the utmost economic importance because most of the improvements secured by plant breeding depend upon it. On account of this practical importance, and also scientific importance, it is worth while, for the sake of ready reference, to learn the names of the various parts of the flower and of the various kinds of flowers and flower clusters.

Structure of the Flower.—Most flowers have a stalk and four kinds of floral parts, the *sepals*, *petals*, *stamens*, and *pistil*. *Trillium* (Fig. 64) is a good example; but the *Geranium*, Mustard, Violet, and hundreds of others can be examined at one season or another.

In *Trillium* there are, at the outside, three green sepals which, taken together, are called the *calyx;* next beyond the sepals are three large white petals which, taken together, are called the *corolla;* beyond the petals are six more or less yellowish *stamens;* and in the center is one *pistil* with three curving lobes at its top.

The sepals, petals, and stamens are generally regarded as modified leaves; and a pistil may consist of a single modified

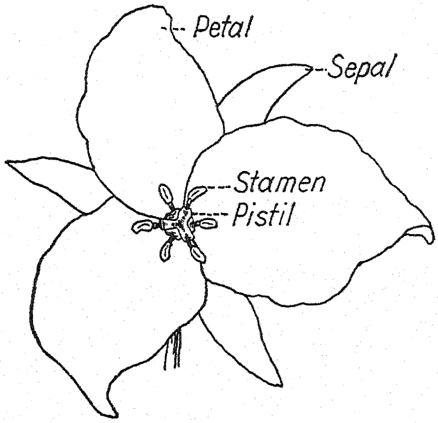


FIG. 64.—Flower of *Trillium*, showing three sepals, three petals (much larger than the sepals), six stamens, and one pistil in the center. The stigma of the pistil has 3 lobes. Two-thirds natural size.

leaf or may be made up of two or more modified leaves joined together. The modified leaves which make up the pistil are called *carpels*. The end of the stem upon which the parts of the flower are borne is called the *receptacle*.

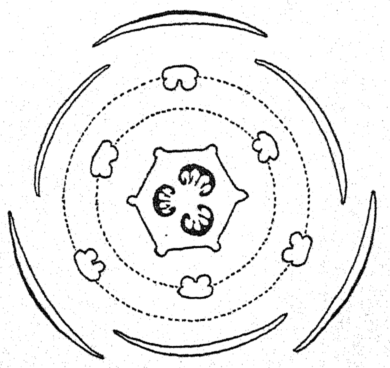


FIG. 65.—Floral diagram of *Trillium*, showing three sepals, three petals, six stamens in two cycles with three stamens in each cycle, and one pistil made up of three carpels so completely grown together that their boundaries are not easily seen.

In *Trillium* the parts of the flower are in threes, and three is the commonest number in the floral plan of the Monocotyls (Fig. 65).

It will be noticed that the petals come between the sepals. A closer examination will show that the six stamens are in two *cycles* with three stamens in each cycle, the three outer stamens alternating with the petals, and the three inner ones alternating with the three outer. There is only one pistil, but the three lobes at its top alternate with the inner stamens.

The tendency of the parts of a flower to alternate in this way is so strong that exceptions to the rule are not numerous. Floral diagrams are instructive and the student should be able to make a diagram of every flower studied.

No flowers are more familiar than the Lily and the Tulip. In these, and in many more, there is no differentiation into green sepals and colored petals. All these parts are colored alike, and all are called *petals*. The calyx and corolla are called the

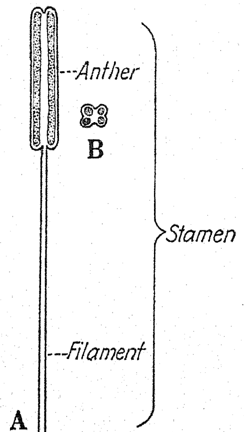


FIG. 66.—Stamen of Lily; *A* showing filament and anther; *B*, a cross-section of the anther showing the 4 microsporangia. About natural size.

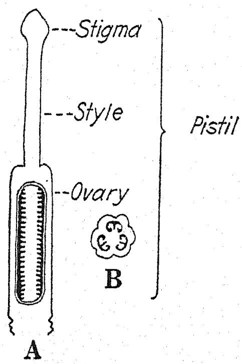


FIG. 67.—Pistil of Lily; *A*, showing ovary, style, and stigma, the lower part of the ovary with the wall cut away to show the ovules inside. *B*, Cross-section of ovary showing ovules. About natural size.

floral envelopes; sometimes they are called the *perianth,* but some prefer to use this term only when the parts are alike, as in the Lily.

The stamen is made up of two parts, a stalk, or *filament,* with an *anther* at the top (Fig. 66). The anther is the male part of the flower. A cut across a lily anther will show that it has four chambers, each containing a powdery mass of *pollen grains.* The pollen grains are called *microspores,* because they are so small, and each of the four chambers is called a *microsporangium* (plural, *microsporangia*). The *-angi-* part of the word means

chamber and the ending *-ium* means the *place where.* So the long word means the chamber where the miscrospores are (Fig. 66).

The pistil is made up of three parts, the *ovary, style,* and *stigma* (Fig. 67). The ovary contains numerous *ovules* which finally become seeds. If the ovary be cut across, it will be seen that there are three chambers extending throughout its entire length, and containing ovules large enough to be seen with the naked eye (Fig. 67). The ovule contains four or more *megaspores,* usually just four, and is called the *megasporangium,* meaning the chamber where the large spores are. A transverse section of the flower bud is interesting. It serves as a floral diagram and, at the same time, shows the exact shape and relative size of the different parts (Fig. 68).

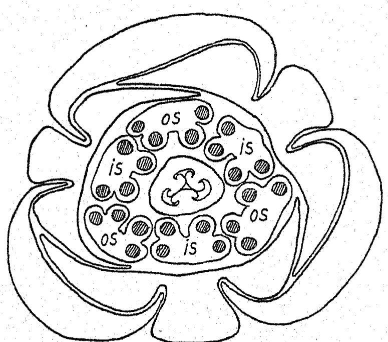


FIG. 68.—Cross-section of bud of Lily, with six petals, 6 stamens (the three in the outer cycle marked *os,* and three in the inner cycle marked *is*), and one pistol. × 6.

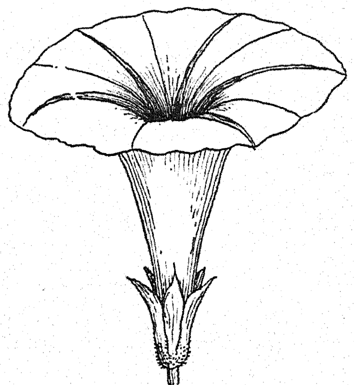


FIG. 69.—Flower of Morning Glory, showing calyx and sympetalous corolla. Two-thirds natural size.

Many flowers do not have separate petals, the corolla being in one piece. The Morning Glory is a good example of this type (Fig. 69). A corolla of this kind is called *sympetalous,* meaning that the petals are all in one piece; or it is called *gamopetalous,* meaning that the petals—imagined to have been separate at some time—have become united. It can be seen that the corolla is marked by five bands of different color or thickness, so that it looks as if five petals might have become united by their edges to form a funnel-shaped tube.

There are only five stamens in the Morning Glory. In *Trillium* there are twice as many stamens as sepals or petals, and they are in two circles, or *cycles*. In the Lily there are six stamens in two cycles and, while the perianth is not differentiated into sepals and petals, there are six parts in two cycles, just as in *Trillium* where the three sepals are green and the petals, white. In the Morning Glory one of the cycles of stamens has been lost. All of the most highly developed flowers have lost one of the two cycles of stamens, usually the inner cycle, as in the Morning Glory.

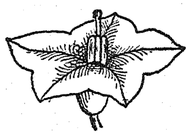


FIG. 70.—Flower of Potato, showing sympetalous corolla, three of the five stamens with the style and stigma projecting above them. Natural size.

In the Potato, Bittersweet, and Tomato, all of which belong to the Potato Family, the corolla is sympetalous, but it has five distinct lobes, and the five stamens alternate with these lobes. In the Morning Glory the corolla flares like the bell of a cornet; but in the Potato Family the lobes of the corolla are almost at a right angle with its tubular part (Fig. 70).

In the Mint Family, represented by such familiar forms as Catnip, Spearmint, and Peppermint, the corolla has two lips, with two lobes in one lip and three in the other. The calyx has five lobes, but its lower part forms a tiny cup: there are only four stamens and the ovary has four lobes, showing that it consists of four parts (Fig. 71). The calyx and corolla still show the original plan of five parts; but one cycle of stamens has been lost, and one stamen has been lost from the remaining cycle. The four-lobed ovary also indicates that one part has been lost; but reduction in the number of parts in the ovary takes place so early in the history of flowers that most of them have fewer parts in the ovary than the number of sepals, petals, or stamens.

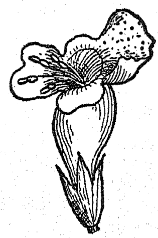


FIG. 71.—Flower of Catnip with two-lobed (two-lipped) corolla, the lobe at the left with one notch, indicating that it represents two petals, while the lobe at the right represents three petals. × 2.

The flower of the common Mustard is interesting because it shows an intermediate stage between two cycles of stamens and one cycle. The flower is built on the plan of four, with four

sepals, four petals, one cycle of four good stamens, and one cycle with two short stamens and two little rounded knobs which do not produce any pollen. But they occupy the position of the two missing stamens and exude a nectar which attracts insects.

The Cabbage, Turnip, and the Radish have flowers practically identical with those of the Mustard; in fact nearly all of the Mustard Family show four long stamens and two short ones. The ovary is made up of two parts indicated by two chambers. But the two missing parts of the ovary are marked, as in the stamens, by little rounded knobs which produce nectar.

The orchids, although largely tropical, are widely known from the displays in park greenhouses and in florists' windows. Some of the most beautiful of all flowers belong here. *Cattleya* is one of the most familiar of the hothouse forms. It is not strange that the curious shapes and beautiful colors have made these flowers objects of interest, even to those who have made no special study of botany.

A few of the 7,000 species of orchids belong to the temperate zone. The Lady Slipper and Ladies' Tresses are rather common in the United States.

The whole Orchid Family shows the floral plan of three, with three sepals, three petals, and an ovary made up of three parts; but one cycle of stamens is always lacking and the remaining cycle is rarely complete. Usually there are only two stamens and sometimes only one.

Many flowers have numerous petals, stamens, or ovaries. In these cases the parts are not in cycles, with three, four, or five parts in a cycle, but are arranged spirally on the flower axis, which is more or less elongated in the region which is producing numerous parts.

In the Apple the stamens are numerous; in the Rose there are five sepals, but the petals, stamens, and ovaries are numerous; in the Strawberry there are five sepals and five petals, but the stamens and ovaries are numerous. In some flowers all four sets may have numerous parts; in some, one set may have settled down to a definite number, while the other three still have numerous parts; two may have become definite and cyclic, while the other two are still spiral; or the spiral character may appear in only one set. The spiral arrangement and indefinite number of

parts in a set go together. The spiral arrangement is easily seen in a Pine cone.

The change from spiral to cyclic arrangement is brought about by a gradual shortening of the flower axis, so that the turns of the spiral become closer and closer together until, finally, there is a ring, or cycle, instead of a turn of a spiral. When the cyclic condition is reached, the number of parts becomes definite and we have flowers with a floral plan of three, four, or five parts in a set.

Flowers with one or more of the four sets in the spiral condition are lower in the scale of development than those which have become cyclic; and flowers which have five cycles are lower than those with four cycles, since those with four have gone through the five-cycle stage and have lost one cycle of stamens.

If the parts of each set—sepals, petals, stamens, pistils—are alike, the flower is *regular;* but if the parts, especially parts of the corolla, are not alike, the flower is *irregular.* The Lily is regular; but the Violet, Sweet Pea, and the Bean, with some of their petals very different from the others, are irregular. In the scale of development, irregular flowers are higher than the regular.

Incomplete Flowers.—One or more of the sets—sepals, petals, stamens, pistils—may be lacking. The sepals and petals are often lacking, as in Grasses and Willows. Flowers which lack any of the four parts are *incomplete;* but if they have stamens and pistils, they are *perfect,* even if they lack both calyx and corolla. Flowers with stamens and pistils in the same flower are called *bisporangiate,* because they have both stamens (*microsporangia*) and ovules (*megasporangia*).

A flower with stamens, but no pistil, is called a *staminate* flower; and one with a pistil, but no stamens, is called a *pistillate* flower. Both staminate and pistillate flowers may or may not have a calyx and corolla.

If the staminate and pistillate flowers are on the same plant, the plant is *monoecious;* but if they are on different plants, the plant is *dioecious.* Corn, with its staminate tassel at the top and the pistillate ear with its long silky styles and stigmas lower down, is a good example of the monoecious type. The Willow, with staminate flowers on one tree and pistillate flowers

on another, illustrates the dioecious condition. The *Begonia*, Alder, and Pine are other examples of monoecious plants. The Poplar, Sassafras, and Juniper are dioecious. In monoecious and dioecious plants, the male and female flowers usually look very different, as in the Willow (Fig. 72).

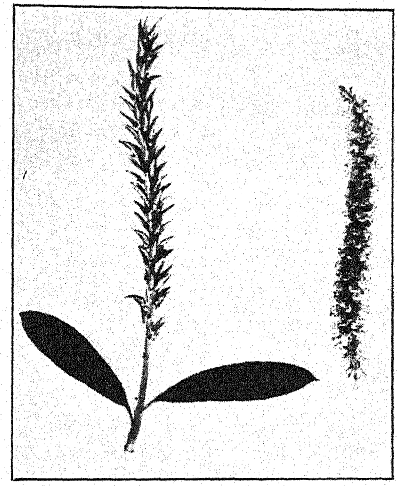


FIG. 72.—Catkins of Willow. The female catkin (on the left) may be erect or drooping. The male (on the right) is drooping when mature. About natural size.

Most flowers are bisporangiate; many are monoecious; and comparatively few are dioecious.

Flower Clusters.—Where there is a single flower at the top of the stem, as in *Trillium*, or where there is only one flower in the axil of an ordinary leaf, as in the Poppy (*Papaver somniferum*), the flower is said to be *solitary;* but when the flowers are closely grouped we have various kinds of flower clusters, called *inflorescences.*

In an early stage the flower is a bud, and, as we have already noted in the study of stems, the bud is an undeveloped branch. The flower may be regarded as a very much shortened and modified branch bearing modified leaves—the sepals, petals, stamens, and pistils. On an ordinary branch one finds a bud at the tip and several buds along the sides, the buds along the sides coming from the axils of leaves; but flower buds seldom occur in both positions on the same plant. The flowers are either at the top, *terminal*, or along the sides in the axils of leaves, *axillary*, but not in both positions. If the flowers are axillary, the growth of the branch is not stopped by the production of flowers and the inflorescence is called *indeterminate*, meaning that the production of flowers does not terminate the growth of the branch. This is the most usual case. If the flower bud is at the end of the branch, it stops the growth of that branch and the inflorescence is called *determinate.*

Indeterminate Flower Clusters.—The principal kinds of indeterminate flower clusters are the *raceme, corymb, umbel, spike, head spadix, catkin,* and *panicle.* The leaves from the axils of which the individual flowers of the cluster are borne are more or less reduced in size and are called *bracts.* Often the bracts are very small, and in many cases they are entirely lacking. In the whole series the oldest flowers are at the bottom, and the buds are at the top in elongated clusters; and in flat-topped clusters the buds are in the middle, with the oldest flowers at the outside. Conventional diagrams will be used to illustrate the various kinds of clusters.

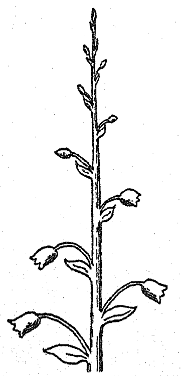


FIG. 73.—Diagram of a raceme.

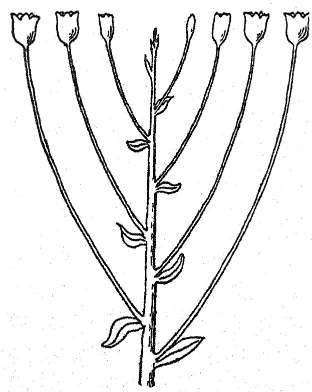


FIG. 74.—Diagram of a corymb.

In a *raceme* the individual flowers, each with its own flower stalk, come from the axils of the reduced leaves on the sides of the elongated stalk of the whole cluster (Fig. 73). The Lily of the Valley and the common red Currant are familiar examples. In the Shepherd's Purse the bracts are entirely lacking and the raceme continues to produce flowers, fruits, and seeds throughout the season.

In the *corymb* the flowers come from the axils of leaves along the stalk of the cluster, as in a raceme; but the stalks of the lower flowers are much elongated and those above less and less elongated, so that the cluster has a flat top (Fig. 74). The Hawthorn has its flowers in corymbs.

In the *umbel* the separate flower stalks are so crowded that they seem to come from the same place at the top of the stem and spread out so as to form a flat-topped cluster. The Carrot Family is called the Umbelliferae because its flowers are in umbels. The *umb-* part of the word is the same as in umbrella, and the name was given because the stalks of the individual flowers of the cluster radiate like the bows of an umbrella (Fig. 75).

The *spike* is like the raceme, except that the individual flowers have no flower stalks. When a flower or a leaf has no stalk, it is *sessile*. The common Plantain on our lawns furnishes a good example of the spike (Fig. 76). The Mullein has a very large spike with yellow flowers.

In the *head* the flowers are sessile, or nearly so, and the flower axis is so much shortened that the

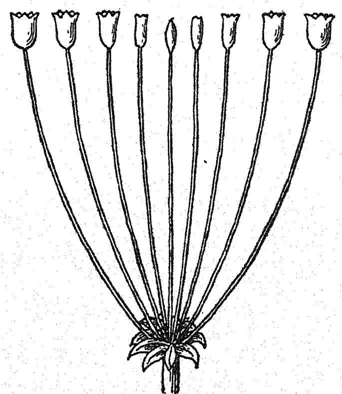


Fig. 75.—Diagram of an umbel.

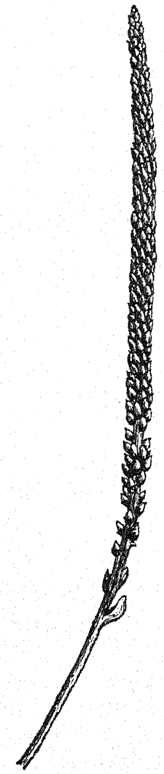


Fig. 76.—Spike of Plantain, one-half natural size.

flowers are crowded together (Fig. 77). The head is like a much shortened spike. This is a very familiar form of flower cluster, illustrated by the Dandelion, various Asters, Goldenrods, Sunflowers, Button Bush, Red Clover, and many others.

The *spadix* is like the spike, except that the axis is fleshy (Fig. 78). The Calla Lily and Jack-in-the-Pulpit are familiar

examples. In greenhouses, various plants related to the Calla Lily will be flowering at all times of the year.

The *catkin* is like a spike with scaly bracts, or it may be like a raceme. In either case, whether the flowers are sessile or

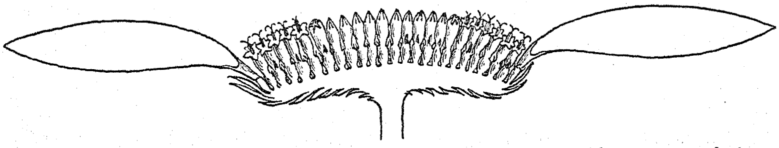


FIG. 77.—Diagram of a section of the head of a Sunflower. About natural size.

have short stalks, they are very much crowded. The Willow, Poplar, Alder, and Birch have their flowers in catkins (Fig. 79). In the Alder and Birch the catkins are nearly mature in late autumn, and they remain in this condition throughout the winter.

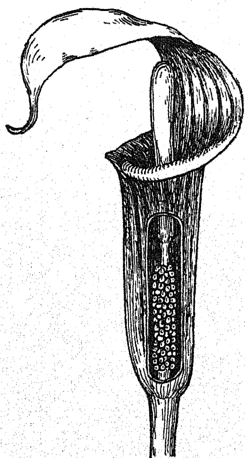


FIG. 78.—Spadix of Jack-in-the-Pulpit. One-half natural size.

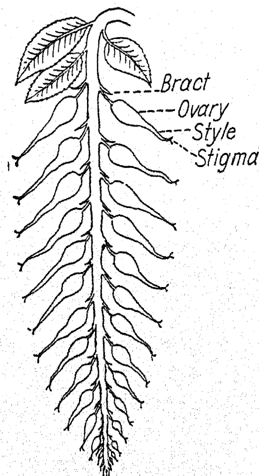


FIG. 79.—Diagrammatic view of a pistillate (female) catkin of Willow. Natural size.

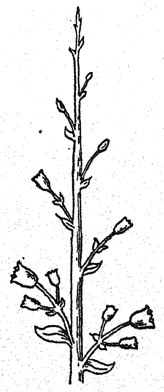


FIG. 80.—Diagram of a panicle.

The *panicle* resembles a raceme (Fig. 80). If the stalks of the lower flowers of a raceme should branch, so that each one would become a small raceme, the cluster would be a panicle. It might be called a compound raceme. The Grape and Horse Chestnut will illustrate this type of flower cluster.

The various kinds of flower clusters intergrade, so that it may be difficult to decide whether some particular cluster should be called a raceme or a spike. Theoretically, one has merely to decide whether the individual flowers of the cluster have stalks or not; but, practically, it may not be easy to decide whether there is an extremely short stalk or none at all. How much does a *spike* need to be shortened before you call it a *head?* Use your own judgment in deciding. How fleshy must a *spike* become before you call it a *spadix?* Use your own judgment. How scaly must a *spike* become before you call it a *catkin?* Here, again, use your own judgment. In many cases it is an arbitrary matter whether a cluster be referred to one category or another. It is better to look at the cluster and decide for yourself, even if you do not pick the same name some one else has picked, than to let the book do all your thinking for you.

A long time ago, before the days of laboratories, some learned men were disputing as to the number of teeth a horse has. They ransacked the library and found conflicting accounts. Finally, a young man suggested that they look at a horse. It was good advice. Look at the flower clusters and follow the same method throughout your study.

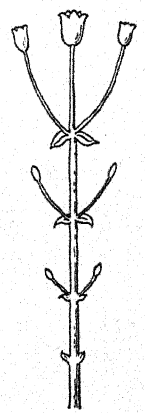


FIG. 81.—Diagram of a cyme.

Determinate Flower Clusters.—In the determinate type of flower cluster there is always a flower at the top of the main flower stalk, so that the growth of the main stalk is stopped, or terminated, by the production of that flower at the top. The oldest flower is at the top, with the younger ones at the sides. If the cluster has a flat top so that, at first sight, it looks like a corymb or umbel, it is easily distinguished by the fact that the oldest flowers are at the center, with the younger ones at the outside, while in the corymb and umbel the youngest flowers are at the center and the oldest ones at the outside.

A flower cluster with the oldest flowers at the top of the main flower stalk, or in the middle of a flat-topped cluster is called a *cyme* (Fig. 81). The Hydrangea and Elder are good examples of this type.

If the separate flowers of a cyme are very much crowded, the cluster is called a *fasicle.* The Sweet William and other species of *Phlox* furnish examples.

If the individual flowers of a cyme are still more crowded, so that the cluster looks like a head, it is called a *glomerule.* The cluster, however, is distinguished from the head by the fact that the oldest flowers are in the center, with the youngest at the outside. The Dodder has this type of cluster.

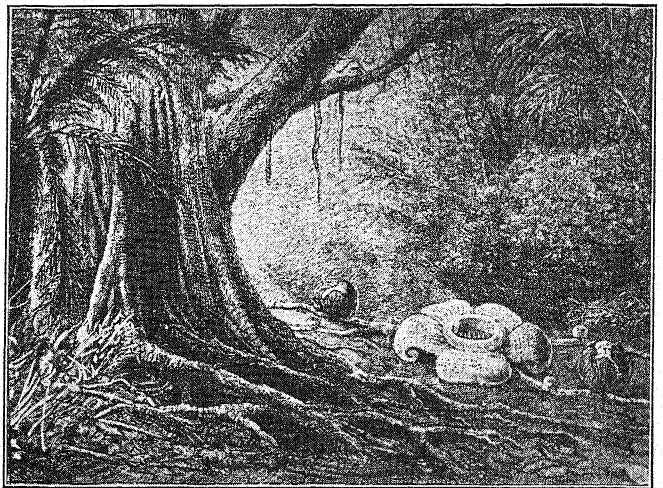


FIG. 82.—Immense flower and some buds of *Rafflesia padma* in Java, growing on roots on the surface of the ground. The flower is about 20 inches in diameter In some species the flower is twice as large. (*After Kerner.*)

The terms, fascicle and glomerule, are not very much used. Most botanists apply the term, cyme, to all three of the determinate clusters; but they may call the fascicle a compact cyme and the glomerule a dense cyme.

Try to classify all the flower clusters you see in the field, at home, at the florists', and in greenhouses.

Some Remarkable Flowers.—Some flowers are remarkable for their size, others for their shapes or colors, and others for their flower clusters or their behavior.

Many would select *Rafflesia* as the most remarkable of all flowers. This immense flower, weighing about 15 pounds and measuring about 3 feet across, is a native of Sumatra. It is

parasitic, getting its nutrition from a host plant and, consequently, needing no leaves or other green parts. The seed falls on the host plant, germinates on the bark, and produces directly a flower bud which develops into the big flower. The color is yellowish orange with pinkish spots (Fig. 82).

The Goose Flower, also called the Dutchman's Pipe, is famous for its grotesque flowers, the peculiar shapes of which have

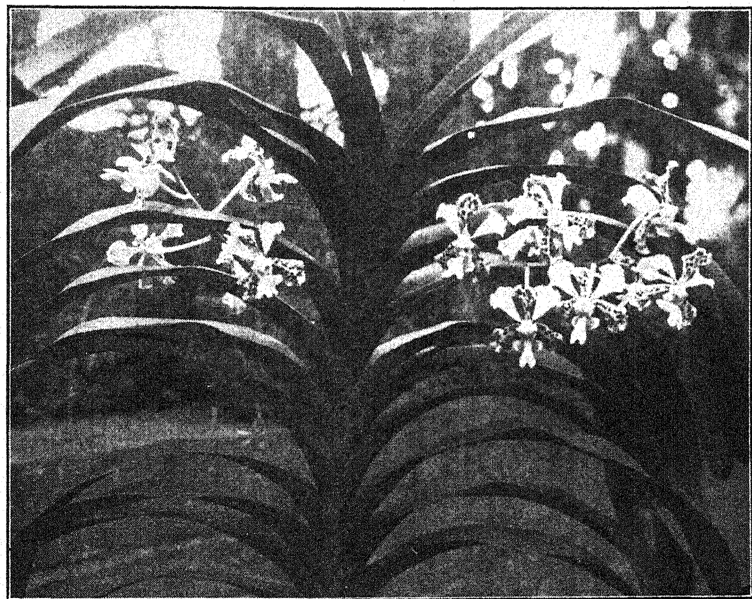


FIG. 83.—*Vanda*, an Orchid.

suggested the common names. The species with the largest flowers are tropical; but forms with the flowers smaller, but just as peculiar, are native as far north as Ohio. The large inflated calyx is the conspicuous part of this flower. In the tropics children use the large flowers for caps.

Orchids furnish endless variety in shape and color. Any greenhouse will have some, and they are all remarkable. There are about 7,000 kinds of orchids (Fig. 83).

The Indian Pipe lives entirely upon decaying organic matter. The whole plant is pure white and is sometimes called the Ghost

Plant. The shape of the plant, with its single nodding flower, suggested the name, Indian Pipe. It is found throughout most of the United States.

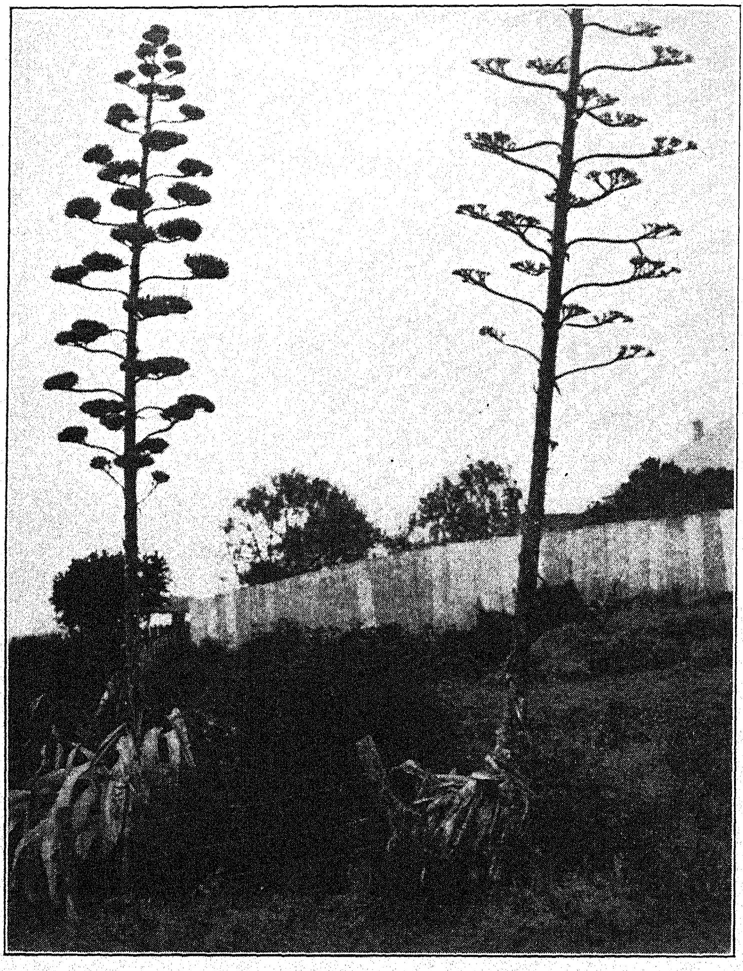


FIG. 84.—The Century Plant. The flower cluster on the left is over 20 feet in height. The one on the right, with dead leaves at the base, is older and has shed most of its seeds. It is about 30 feet in height.

Many flowers which, taken alone, are not out of the ordinary, grow in remarkable clusters. In some Palms the flower clusters

are of immense size, reaching 10 feet or more in length, with thousands of crowded flowers.

The largest flower cluster is that of the Century Plant, which reaches a height of 30 feet and, at a distance, looks like a pine tree (Fig. 84). The name, Century Plant, was given on account of the mistaken idea that it does not flower until it is 100 years old. In Mexico where it is extensively cultivated for its juice from which an intoxicating drink is made, it is raised

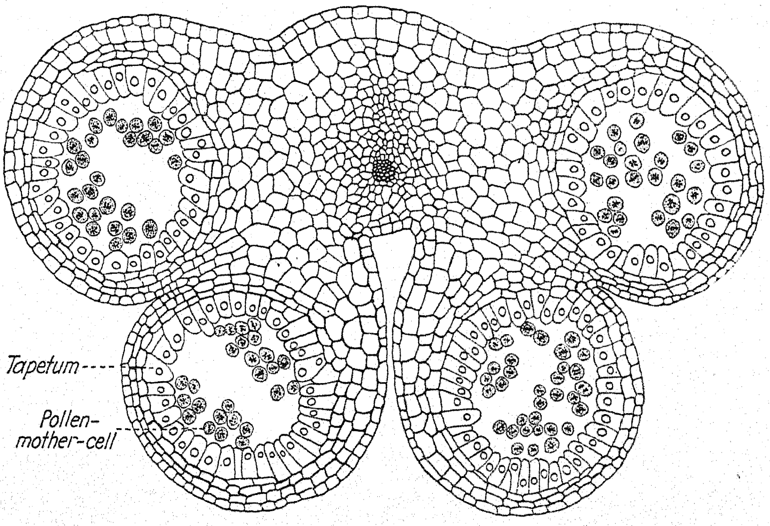


FIG. 85.—Cross-section of an anther of Lily with four microsporangia, each surrounded by a tapetum and containing microspore—mother cells (shaded). × 50.

from suckers 3 or 4 years old. These are planted and in 6 or 7 years the flower bud begins to expand; but they cut it out, leaving a hole as large as a milk pail. The juice which would have supplied the great flower cluster flows into the hole and is collected every day or two for several weeks. It soon ferments, and is then called *pulque*, the Mexican wine.

Microscopic Structure.—Much can be seen by cutting across an anther or an ovary with a sharp knife and examining the cut surface with a pocket lens; but very thin sections are necessary for details. A thin section of a young anther of a Lily, cut transversely, shows four *microsporangia*, each containing numerous

microspore mother cells (Fig. 85). They are called microspore mother cells because each one produces four *microspores*, usually called pollen grains. Each microsporangium is lined by a nutritive layer (*tapetum*) which passes food material to the growing pollen grains. The four miscrosporangia are in pairs and the wall between the two members of a pair soon breaks down, so that each anther contains only two chambers instead of four (Fig. 86). At the same time the four microspores of each group

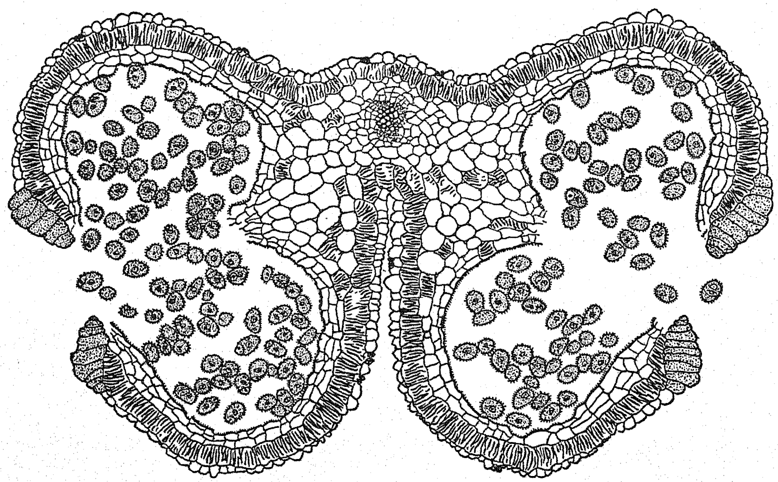


FIG. 86.—Cross-section of mature anther of Lily just as the pollen grains (microspores which have begun to germinate) are being shed. × 30.

fall apart, and each microspore forms two spore coats, the outer one becoming marked with patterns which are very different in different plants.

The yellowish microspore, or pollen grain, of a Lily is barely visible to the naked eye when placed in a favorable light on a black background; but modern microtechnique has become so highly developed that 20 or more sections can be cut through a single pollen grain, these sections can be mounted and stained without getting them out of order, a photomicrograph can be made, and then a lantern slide can be made from the photomicrograph. When the lantern slide is thrown upon the screen, the pollen grain has become 10 feet long, with its spore coats and internal structure well marked (Fig. 87).

The principal structures of the pollen grain are the inner spore coat (*intine*), the outer spore coat (*exine*) with its markings, and, inside the spore coats, a *generative nucleus* and a *tube nucleus*. The rest of the interior of the pollen grain is filled with starch and other food material. The pollen grain is usually shed from the anther in this condition; but in some plants the generative nucleus divides, forming two *sperm nuclei*, before shedding occurs.

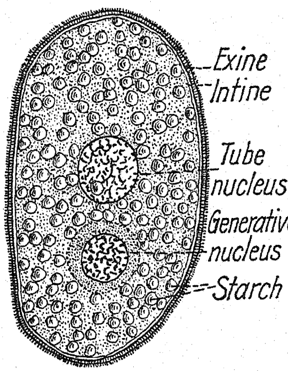


FIG. 87.—A mature pollen grain of Lily. Four pollen grains are produced by each pollen-mother-cell, like those shown in Fig. 85.

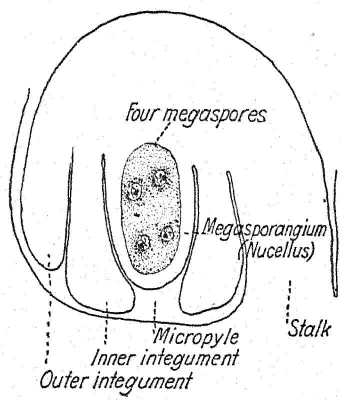


FIG. 88.—Ovule of Lily. The megasporangium, which is the essential part of the ovule, contains four megaspores which are not separated by walls. × 80.

If the ovary of a Lily be cut transversely, as we have already seen, it generally shows six *ovules* which, later, are to become seeds. A longitudinal cut shows that the ovules are very numerous (Fig. 67).

A thin section of one of the ovules shows the details of its structure (Fig. 88). There is a *megasporangium* containing four *megaspores*. Surrounding the megasporangium is an *inner integument* and an *outer integument*. The integuments do not come completely together, for there is a small pore, the *micropyle*, leading to the megasporangium.

The four megaspores divide, giving rise to eight nuclei which assume characteristic positions. In most plants, one of the megaspores becomes large and absorbs the other three (Fig. 89). The large one then divides until it has eight nuclei. In both cases,

the eight nuclei, with their names, enrich our rapidly growing vocabulary.

The whole structure inside the megasporangium is called the *embryo sac* (Fig. 90). One of the eight nuclei surrounds itself with some of the nutritive material, with which the sac is filled, and becomes the *egg*. The two nuclei nearest the egg become organized as *synergids*. Two more nuclei, one at each end of the sac, are called *polar nuclei*. They come together near the egg and fuse, so that they form one nucleus, called the *endosperm nucleus*. The other three remain at the end of the sac opposite the egg and, on this account, are called *antipodal cells*.

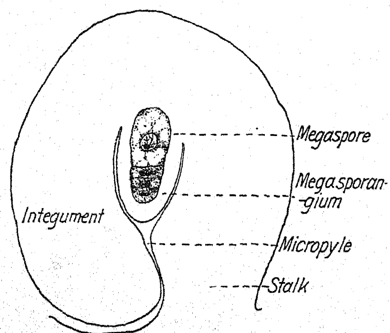


FIG. 89.—Ovule of Fleabane. The megasporangium contains four megaspores, separated by walls. The three megaspores nearest the micropyle are disorganizing and the other megaspore is beginning to develop into the embryo sac. × 100.

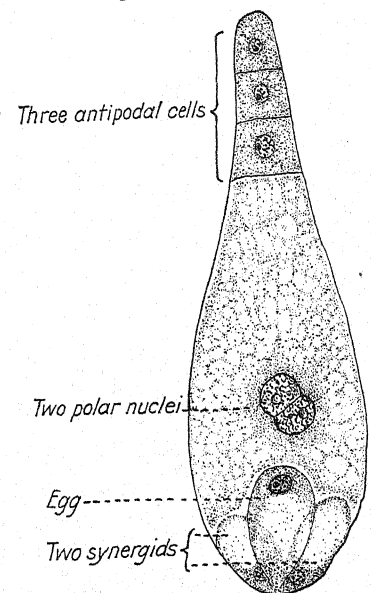


FIG. 90.—Embryo sac of Aster. Such an embryo sac, with its eight parts, develops from a megaspore like the largest one shown in Fig. 89.

Embryo sacs of different plants differ in appearance and differ somewhat in mode of formation; but all of them have an egg, and nearly all have two synergids, two polar nuclei and three antipodals.

The anther produces the pollen grain with its generative nucleus or two sperm nuclei. The ovule in the ovary produces an egg. To start a new plant, the sperm nucleus must be brought into contact with the nucleus of the egg.

Pollination.—In various ways, by wind, by water, or by insects, pollen is brought from the anther to the stigma. The bringing of the pollen to the stigma or, in cone-bearing plants, to the ovule directly, is called *pollination*.

Pollination by Wind.—In many plants, especially low in the scale of development, the pollen is carried by the wind from the anther to the stigma or ovule. The Pine, Fir, Spruce, Hemlock, and that entire group of cone-bearing trees are pollinated by the wind. The Oak, Beech, Hickory, Walnut, Birch, Alder, and many other trees and shrubs belong here, together with grasses, including Corn, Wheat, Oats, and other cereals, Hops, Nettles, and many more. Perhaps, about one-tenth of all seed plants are pollinated by the wind.

The term *anemophilous* (wind loving) is applied to plants which are pollinated by the wind. They generally have small, inconspicuous flowers, with little or no odor, and many of them lack both calyx and corolla.

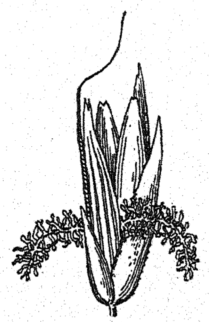


FIG. 91.—Flower of Oat, showing feathery stigma × 2.

Pollination by the wind is uncertain, for the pollen is blown everywhere and nearly all of it is wasted; but wind-pollinated plants produce pollen in such immense quantities that, even with all the waste, some pollen is likely to reach the right spot, and a single pollen grain is enough to enable an ovule to develop into a seed. In a Pine the number of pollen grains is probably several million times as great as the number of ovules, so that most of the ovules become seeds.

When wind-pollinated plants are dioecious, with staminate flowers on one plant and pistillate flowers on another, pollination may become quite uncertain; but in dioecious plants, as in animals, the number of males and females keeps approximately equal, and the plants are likely to grow near each other.

Another thing which increases the probability of pollination is the fact that stigmas secrete a sticky juice which holds any pollen falling upon them. Besides, many stigmas are not only sticky but also feathery, as in grasses (Fig. 91).

Pollination by Water.—There are comparatively few plants in which the pollen is carried to the stigma by water, and these, of course, are plants growing in the water. The staminate flowers are formed under water, but, when the pollen is mature, they break off and rise to the surface. The whole flower then floats, like a little boat, and its anthers brush against the stigmas of the pistillate flowers, which also float on the surface of the water while remaining attached to the plant. *Elodea,* called the Water Weed, very common in ponds, and *Vallisneria,* a European pond weed, but rather common in aquaria, furnish examples of this method of pollination. Some prefer to regard these as wind-pollinated plants, because the staminate flowers are blown about on the surface of the water.

Pollination by Insects.—Most flowers are pollinated by insects and, on this account, are called *entomophilous* (insect loving). Most seed plants belong here. Modifications and adaptations of flowers to insure pollination by insects are so numerous and so remarkable that books have been written on the subject. Modifications to keep away insects which would get the honey without effecting pollination are no less wonderful.

As a general thing, pollination of a stigma by pollen from anthers in the same flower—they call it close pollination—is avoided. Pollination by pollen from another flower on the same plant is better; and if the pollen comes from a flower on another plant, it is still better.

Insects are attracted to flowers by the honey, or nectar, which is produced by nectar glands, usually situated near the base of the stamens. The nectar is at its best when the stamens are shedding their pollen and, consequently, while getting the nectar, the insect becomes dusted with pollen which it carries to another flower, where some of it is brushed off on the stigma. The insect gets the nectar and the flower gets cross-pollination.

Flowers which are pollinated by insects generally have conspicuous corollas, and those which are not pollinated by insects are likely to have inconspicuous corollas or none at all. From this some have concluded that the corolla, as well as the nectar, attracts insects; while others have claimed that the corolla is merely a sign which saves the flower from being overlooked.

If the corolla is removed, insects still come and get the nectar; but whether they come in as large numbers or from as great a distance, is doubtful. If such experiments could be carried out decisively, they would not only prove whether the corolla attracts insects, but they would also prove whether insects can see farther than they can smell.

At any rate, the colors of flowers, usually contrasting sharply with their background, are what we think they should be if they are to attract attention. White is the commonest color, with yellow next and red in the third place. Blue and violet come next and other colors are rare. The commonest colors contrast most sharply with green, which is the prevailing background.

With a black bull's-eye on a light-colored background, the rifleman makes a better score than he could on the same bull's-eye without a good contrasting background. A man who scores well on the rifle range sometimes misses game in the field. In a railway signal the black band on a white ground catches the eye when either color, used alone, might escape notice.

Another thing which indicates that the color attracts insects is that the most brightly colored part of the flower is almost always the one which would be seen by flying insects. If the flower is erect, the inside is likely to be the most brightly colored; but if the flower is nodding, so that an insect from a distance would not see the inside, it is likely to be the outside which has the greatest display of color.

Sometimes the flower itself is inconspicuous, but bracts immediately surrounding the flowers are very showy, as in the Flowering Dogwood and the Poinsettia which is so popular at Christmas time. There is no doubt that insects come to get the nectar, but it looks as if the bright colors do their part in guiding the insects to the flower.

No group of plants shows more numerous or more varied adaptations to pollination by insects than the orchids. Darwin wrote a book on "Fertilization of Orchids by Insects." Of course, he meant "pollination," but the terms *fertilization* and *pollination* were loosely used at that time. Some of the modifications of the flowers have gone so far that a given variety can be pollinated only by some one variety of insect; and, on the other hand, some insects have become so modified that they can get

nectar only from some particular orchid. The flower and the insect have become mutually dependent. In various ways the pollen is deposited on the insect which then visits another flower and brings some of the pollen to its stigma.

Plants more familiar than the orchids show equally curious modifications. *Salvia,* which, with its long racemes of brilliant scarlet flowers, is so popular as a lawn and border plant in late

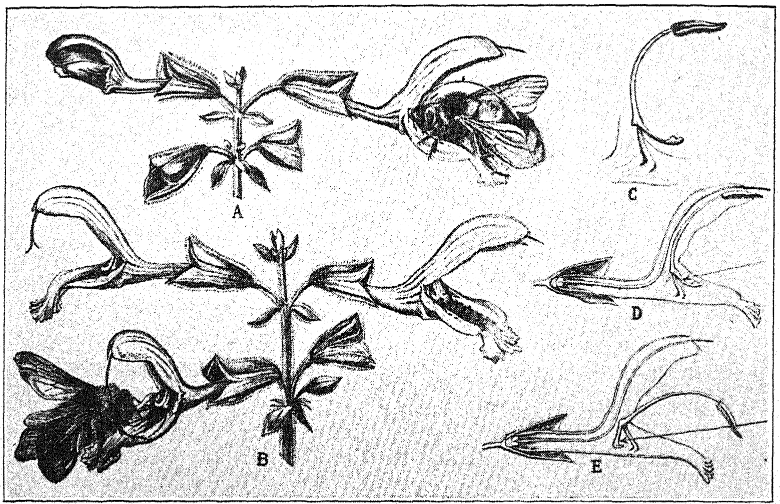


FIG. 92.—Flowers of *Salvia* showing, at *A*, how a bumble bee gets dusted with pollen; and, at *B*, how the pollen is brushed against the stigma; *C* shows the position of the stamen; the arrow in *D* points to the place where the bee touches the lower part of the stalk; and *E* shows the position when the anther is rocked down upon the bee's back. (*After Kerner.*)

summer and autumn, has a very peculiar modification of the stamens. The stamen rocks, as if on a hinge (Fig. 92). In getting to the nectar the insect pushes against the lower part and thus brings the anther down upon its back. When it goes to another flower in which the style and stigma have elongated, the stigma gets dusted with the pollen on the insect's back.

The story of *Yucca* and *Pronuba* is too marvellous for belief, had it not been investigated and confirmed so many times. *Yucca* is a member of the Lily Family, with stiff, swordlike leaves and a great panicle of white, drooping, bell-shaped flowers (Fig. 93). *Pronuba* is a small moth.

The flowers open at night; and the big white cluster is easily seen, even in starlight. The moth gathers a ball of sticky pollen, more than twice as large as its own head, then bores a hole through the ovary wall and deposits some eggs. Next, she goes to the stigma of the same flower and crowds the pollen into a

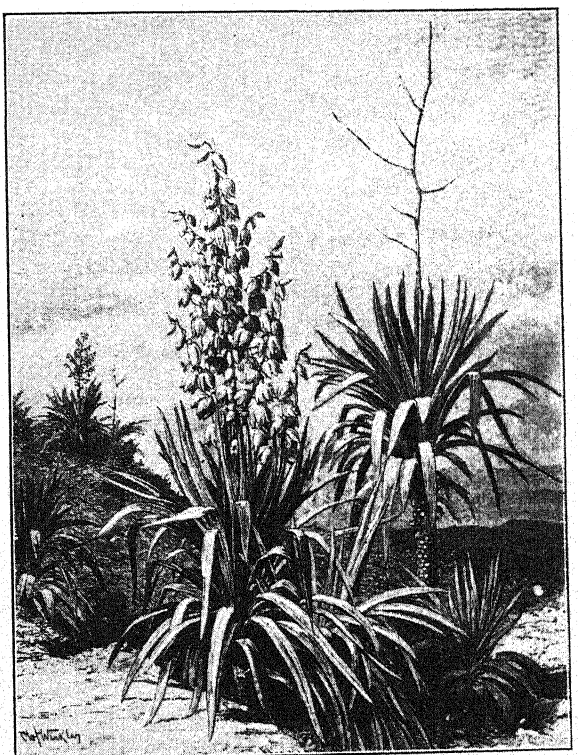


FIG. 93.—*Yucca*, showing the large panicle of flowers. (*After Kerner.*)

depression in its top. The pollen tubes grow down into the ovary, fertilization takes place and the young ovules begin to enlarge. The eggs of the moth hatch in 4 or 5 days and the young larvae feed on the growing *Yucca* ovules, each grub eating about 20 ovules; but the ovules are so numerous that many are left uninjured and develop into good seeds. When the grub is mature, it bites a hole through the ovary wall, crawls out, lets itself down to the ground by a thread and burrows

into the earth, where it remains quiet until the next summer. Two weeks before the time for *Yucca* to bloom, it begins to show signs of life, and, just as the flowers open, the fully developed moth comes out from its cocoon, ready to repeat the process.

The moth does not eat the ball of pollen. Why should she roll it up and stuff it into the depression in the stigma? The *Yucca* is practically dependent upon the *Pronuba* moth for pollination, for it is well known that plants set out for decorative purposes or taken to countries where there are no *Pronuba* moths, do not produce any seed. Where the plants are native, the young larvae would have some small ovules to feed upon even if there were no pollination; but, without seed, the *Yucca* would soon become extinct. It would take a strong imagination to imagine that the moth reasons as follows: If I don't roll up that ball of pollen and stuff it into the stigma, there will be no seed. My own larvae will have enough to eat but, with no seed, *Yucca* will become extinct and Pronubas, with no Yuccas, must also become extinct. Therefore, I will roll up a big ball of pollen, stuff it into the stigma, and make sure that *Yucca* shall set seed and flourish for the benefit of future generations of my race.

This is imagination; but that the moth lays its eggs and pollinates *Yucca* in this peculiar way is a fact which has been observed repeatedly, and which can be confirmed by any student who happens to be living in the southwestern part of the United States or in Mexico, where *Yucca* and *Pronuba* are abundant.

The pollination of some kinds of Figs is no less remarkable. The adaptations in the structure of the Fig to pollination by a small wasp are so extreme that they are hard to explain.

It is well known that flowers, like leaves, vary so much that no two flowers are exactly alike. A flower with a favorable variation is more likely to survive than one which does not have this advantage and, consequently, is more likely to live and propagate itself. In succeeding generations, the variation may become emphasized. Many of the adaptations of flowers to insect pollination may have arisen in this way.

It is interesting to note that cross-pollination was effected artificially long before there was any scientific knowledge of the processes involved.

The Date Palm is dioecious, and, of course, the staminate trees bearing no dates were not cultivated. When Herodotus, the "Father of History," visited Egypt, more than 400 years B.C., he saw priests, with religious processions, carrying the long sprays of staminate flowers from the wild palm and waving them over the opening flowers of the cultivated date-bearing trees. They knew that unless they waved the big staminate clusters over the flowers of the date-bearing trees, there would be no dates. To them, the processions and ceremonies were essential. Today, they still wave the staminate clusters over the young pistillate flowers, but they have dispensed with the ceremonies.

Unwelcome Guests.—The adaptations for preventing visits by insects which would get the pollen without effecting pollination are so numerous and varied that there has been much fanciful writing under such titles as Unwelcome Guests and Unbidden Guests.

The common Catchfly should be cross-pollinated, and such pollination is effected by flying insects. It would be a useless loss if pollen should be taken by small insects, which only crawl up and get pollen which they are not likely to take to another plant. In the middle of each internode of the flowering tip of the plant, there is a broad band of sticky glandular hairs which prevent even large crawling insects from climbing up to the flowers. Gardeners imitate this device by daubing a band of sticky stuff on trees and shrubs to prevent insects from climbing up.

In some plants the calyx has sticky hairs; in some the petals are so sticky that insects cannot get past; and in others there is a fringe of hairs or bristles which blocks the way to any insects except those with a long proboscis.

Snails and slugs can get past the sticky protections, but flowers likely to be visited by these are often protected by sharp hairs or spines which effectively stop such soft animals.

The small flowers which make up the head in the Sunflower Family are rich in honey; but the bracts which surround the whole head are often sticky, so that only flying insects can reach the flowers. Even some of the flying insects may be undesirable. If a calyx and corolla are delicate, some insects, especially bees, will bite through and take the honey without coming into contact with the pollen. Many flowers which might lose their

honey, without getting any return for it, have developed such tough thickenings in the region of the nectar glands, that insects cannot bore through; they must get the honey in a legitimate way, paying for it by getting dusted with pollen which they take to neighboring flowers.

Some of the Sunflower Family, during early stages in the development of the flower cluster, are very susceptible to attacks of beetles which bore in and destroy whole clusters. In some of

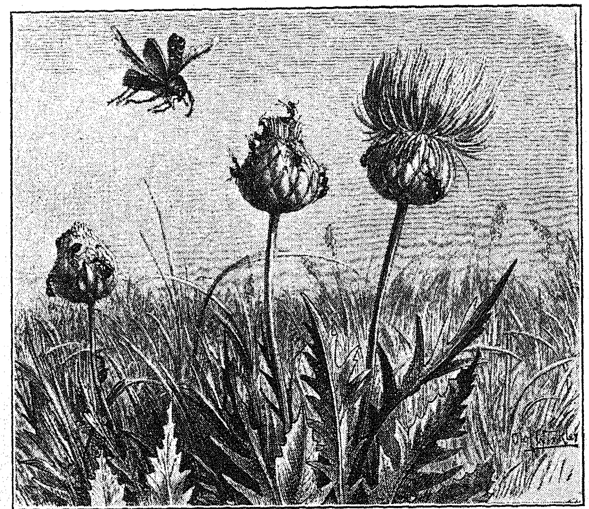


Fig. 94.—A South African flower (*Serratula*), related to the Thistle. The ants are able to fight off the large beetles. (*After Kerner.*)

these plants the bracts surrounding the whole cluster secrete a very pure honey which, as it dries, leaves small crystals of sugar. Ants are very fond of this sugar and may be found to the number of twenty or more on the bracts of a single cluster. When an enemy appears, they assume a threatening position and fight off even large beetles by squirting formic acid at them (Fig. 94). By the time the ants have got all the sugar, the flowers have passed the stage at which they are in danger from beetles, and other insects then come and do the pollinating.

Fertilization.—After the pollen, in one way or another, has reached the stigma, the pollen grain germinates. It puts out a tube which grows down through the stigma and may grow

through the style; but the style is often hollow, so that the growing pollen tube merely clings to its inner surface as it advances toward the ovule. Upon reaching the ovule, the pollen tube enters the micropyle and penetrates the embryo sac (Fig. 95).

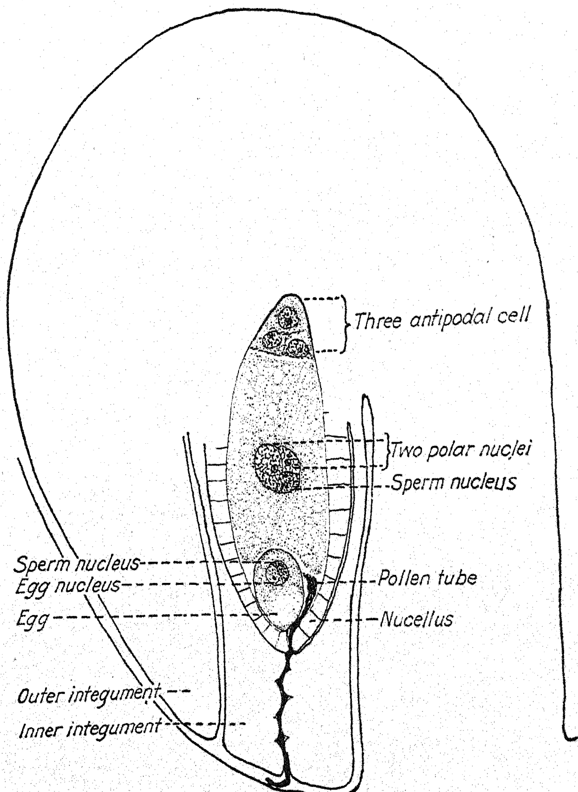


FIG. 95.—Fertilization in Lily.

If the pollen grain, at the time of shedding, has three nuclei, one is the tube nucleus and the other two have already become sperm nuclei; but if the grain had only two nuclei, the division which produces two sperm nuclei takes place while the pollen tube is advancing toward the ovule.

In both cases when the tube enters the micropyle, it has two sperm nuclei. The tube now presses into the embryo sac and

discharges the two sperm nuclei, one of which enters the egg and fuses with its nucleus, while the other fuses with the endosperm nucleus.

The fusion of a sperm nucleus with the nucleus of the egg is called *fertilization*, and the fusion of the other sperm nucleus with the endosperm nucleus is often called fertilization of the endosperm. Since there are two fusions, the whole process has been called *double fertilization*. As a result of the fertilization of the egg, an embryo is formed which develops into a new plant like the parent, and, from the fusion with the endosperm nucleus, there is developed a mass of cells, called the endosperm, which nourishes the embryo during its early stages.

Since the endosperm nucleus is the product of the fusion of the two polar nuclei and the sperm nucleus fuses with this product, the process is usually called *triple fusion*.

Usually, the most immediate and conspicuous result of fertilization is the wilting and falling of the petals. Florists remove the stamens of open flowers of the Easter Lily, thus preventing pollination and fertilization and, consequently, delaying the wilting and falling of the petals. Besides, the white petals are not disfigured by the yellow pollen. Buds which open later shed their pollen and the petals wilt much sooner.

Hybrids.—In most cases fertilization takes place only between plants of the same species or variety; but, occasionally, it takes place between different varieties or different species and, rarely, between plants even more remotely related. Plants developed from such crossings are called *hybrids*.

It is interesting to note that the pollen usually determines the character of the endosperm. If Corn, which, when pollinated with its own pollen or with that of plants of its own kind, would produce yellow pollen grains, be pollinated with pollen from a plant which, if pollinated with its own pollen, would have red grains, the resulting hybrid will have red grains. If some of the stigmas of an ear of corn be pollinated with pollen from a red variety and other stigmas of the same ear be pollinated with pollen from other varieties, the ripe ear will have red grains and grains of various other colors. In Field Corn the endosperm contains starch, and in Sweet Corn it contains sugar; but if the stigmas of Field Corn be pollinated with pollen from the Sweet

Corn, the result will be Sweet Corn ears on the Field Corn stalks; and, in the same way, Field Corn ears may be made to grow on Sweet Corn plants.

A hybrid may not seem to show any blending of characters, but it may show some characters of one parent and some of the other. More than 60 years ago (1866) Gregor Mendel, an Austrian monk, published the results of extensive experiments in crossing garden Peas. He could not make botanists take any interest in his work, but he tried to console himself with the remark, "my time will come"; and it did come 34 years later, when a great investigator found the obscure publication and brought it to the attention of the scientific world. The principles are so fundamental that more progress has been made in plant breeding since the year 1900 than in all previous time put together; and the name of Mendel with the terms Mendelism, Mendelian hybrid, Mendelian factor, and Mendelian ratio have become a necessary part of the vocabulary of every plant breeder.

For crossing, Mendel selected plants with contrasting characters. For example, he would cross a plant which has wrinkled seeds with one which has smooth seeds; a tall plant with a short one; and so with other contrasting characters. He then noted the behavior of the contrasting characters in the hybrids.

In the first generation resulting from crossing tall and short plants, all the hybrids are tall. But when these hybrids are pollinated with their own pollen, the second generation does not behave in the same way. One-fourth of the plants are short, and these short plants, when self-pollinated, continue to produce only short plants. The other three-fourths of the plants are tall and look alike, but they do not behave alike, for one-third of them remains tall in generation after generation, when pollinated with their own pollen; but the other two-thirds, when pollinated with their own pollen, produce tall and short plants in the ratio of one short plant to three tall ones. This is the Mendelian ratio, which Mendel expressed as follows:

$$A + 2Aa + a$$

In this ratio, A means tall plants and a means short ones. It also means that one-fourth of the plants, A, when self-pollinated, produce only tall plants; one-fourth, a, only short plants;

and one-half, $2Aa$, continue to break up in the ratio $A + 2Aa + a$.

The ratio, expressed graphically, for a cross between a parent with smooth seeds and one with wrinkled seeds, may be easier to understand (Fig. 96).

Of course, not all varieties and species will cross; but when they can be crossed and the hybrids are fertile, rapid improvements are possible. Instead of experimenting at random as in

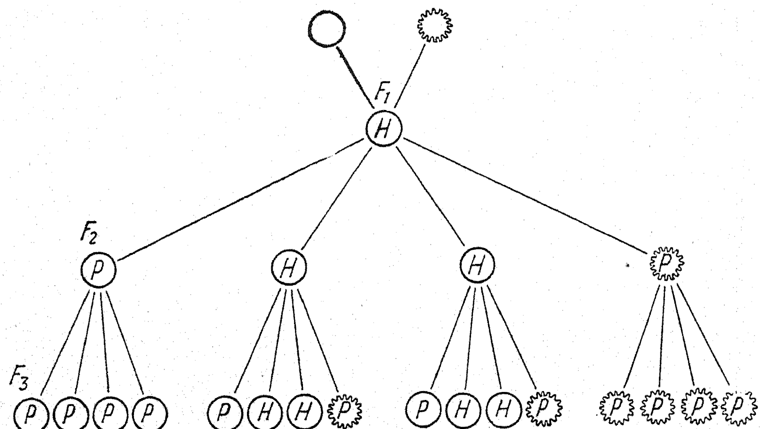


FIG. 96.—Diagram showing how garden Peas behave when a variety with smooth seeds is crossed with a variety which has wrinkled seeds. The plant resulting from this cross is called the F_1 generation. The next generation is called the F_2 generation; etc. In the diagram, P means pure; and H means hybrid. All the seeds on any one plant are alike: They are all pure wrinkled, pure smooth, or hybrid smooth. Those which are pure, when self pollinated, remain pure; the hybrids, when self pollinated, produce plants with smooth and wrinkled seeds in the proportion of three smooth to one wrinkled.

the past, the plant breeder can now select desirable characters and combine them. Since 1900 there has been great progress in the improvement of Corn, Wheat, Oats, Alfalfa, and many other plants of great economic importance.

Many plants hybridize naturally. The Willow (*Salix*) is a good example. Some of its hybrids are fertile and will cross with other Willows; and these hybrids will cross with others. When various members of a group cross so readily, it is difficult and often impossible to name plants with any certainty.

In rare cases it happens that plants not only will not cross with any other plants but also when pollinated with their own

pollen do not develop any pollen tubes and no fertilization takes place; but they produce seed without any fertilization. Such plants are called *parthenogenetic*. The common Dandelion is a very familiar example of a parthenogenetic plant. The Hawkweed also develops its seeds without fertilization. Mendel made experiments with the Hawkweed as he did with the garden Peas and was much disturbed because it did not follow his ratio. He did not make any microscopic investigation and, consequently, could not know that all the pollination was in vain, that it produced its seeds without fertilization.

CHAPTER V

THE FRUIT

The fruit naturally follows the flower. Fertilization is a stimulus which not only results in the development of a new plant but also causes profound changes in the ovary and even in parts farther away from the fertilized egg.

As a result of fertilization, the ovary may reach thousands of times the bulk it had before fertilization took place. Measure the ovary of a Pumpkin or Watermelon while the flower is at its best, as it is just before fertilization, and then compare it with the size of the ripe fruit.

In some peculiar cases the mere presence of pollen on the stigma may start the development, even when no fertilization is to follow, as in the seedless Grape; and in other cases, still more rare and peculiar, development proceeds without either pollination or fertilization, as in the Banana, Pineapple, Cucumber and Orange. But these are to be regarded as cases which, for some reason or other, have departed from the usual method of development.

A fruit is as hard to define as a flower. It has been defined as a matured ovary and its contents; but this does not include the Strawberry, in which the delicious juicy part is the swollen end of the receptacle, while the ovaries are merely the little yellow grains which dot the surface.

A mature ovary with its contents, with or without associated parts, would be a better definition, for it would include the Strawberry, Fig, Apple, Pineapple, Artichoke, and other fruits in which the edible part is neither the ovary nor its contents.

If you bring the subject up at the grocery or at the table, you are likely to find great differences of opinion as to whether this or that shall be called a fruit or a vegetable. All will agree that Apples and Oranges are fruits and that Potatoes and Radishes are vegetables, but there may not be such agreement

in regard to Tomatoes, Squash, Rhubarb, and Peppers. If you look in the encyclopedia, you will find many genuine fruits referred to as vegetables; and side dishes are usually called vegetables, even when they are fruits in the strictest sense, like Tomatoes and String Beans.

The term, vegetable, may be even broader. The vegetable kingdom includes all plants, just as the animal kingdom includes all animals. A person is called a vegetarian if he omits meat from his diet.

In spite of some indefiniteness, a true fruit is always a part of the flower and is usually started on its course by the fertilization of the egg.

The grocery will afford material for a study of many fruits. Most fruits, when ready for the table, are mature or nearly mature. The grocer does not have the flowers and the florist does not keep the flowers which yield the grocery fruits; but whenever both flower and fruit can be secured, it is interesting to note the relation between them. The part we eat may be the ovary, as in the Tomato; it may be the end of the receptacle, as in the Strawberry; it may be the end of the stem enclosing the pistils, as in the Apple; it may be bracts surrounding a flower cluster, as in the Artichoke; or it may be something else which has been stimulated to development by pollination or fertilization or both.

Fruits may be classified as fleshy fruits and dry fruits.

FLESHY FRUITS

In fleshy fruits the edible part may be very soft and juicy throughout, as in the Grape; or it may be firmer, especially on the outside, as in the Orange; or it may be soft outside and hard inside, as in the Peach; or it may be rather firm outside with numerous seeds inside, as in the Watermelon; or the fleshy part may be outside the ovary, as in the Apple. Besides, there are clusters of fruits, all belonging to the same flower, as in the Blackberry; and clusters coming from many crowded flowers, as in the Pineapple. And there are fruits not so closely related to the flower, as in the Artichoke.

The various kinds of fleshy fruits have been called the *berry*, *drupe*, *pome*, *pepo*, *aggregate fruit*, *accessory fruit*, and *multiple*

fruit. These various classes will be clear when illustrated by familiar examples.

The Berry.—The Grape is a typical berry. The fleshy juicy part consists of the ripened ovary containing the seeds. Another type of berry, illustrated by the Gooseberry, consists partly of a tender juicy stem and partly of a pistil. The outer part of the seeds also becomes pulpy. The relation of the flower to the mature fruit is shown in Fig. 97. The flower is shown, natural

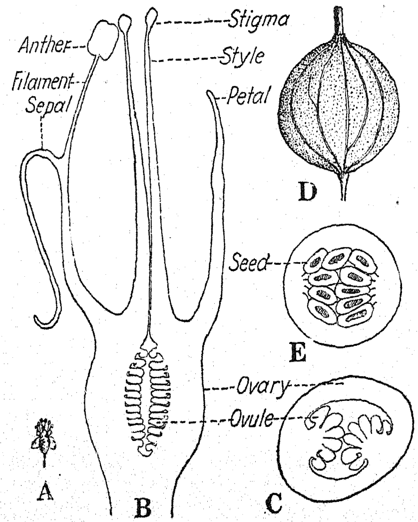


Fig. 97.—Gooseberry. *A*, the flower, natural size, *B*, longitudinal section of flower showing the various parts. × 12; *C*, cross-section of the ovary at this stage, × 12; *D*, ripe Gooseberry, natural size; *E*, cross-section of ripe Gooseberry, showing seeds, natural size.

size, in *A*, of this figure; *B* and *C* show much magnified sections of the flower at this stage; while *D* and *E* show the ripe Gooseberry, natural size. The calyx, corolla, and stamens, dried and withered, remain at the top of the fruit, which becomes very juicy. It often happens, as in this case, that many of the ovules fail to develop into seeds. A comparison of *C* and *E* (Fig. 97) shows that at least half of the ovules did not develop.

The Currant, Grape, Cranberry, Blueberry, Huckleberry, Tomato, Ground Cherry, and Persimmon are berries.

Citrous fruits, like the Orange, Lemon, Grapefruit, and Tangerine, have the outer part harder than the juicy pulp within;

but they are all genuine berries in which the edible part is the ripened ovary.

The development of the Orange, especially the Navel Orange, from the flower is interesting. A diagrammatic longitudinal view

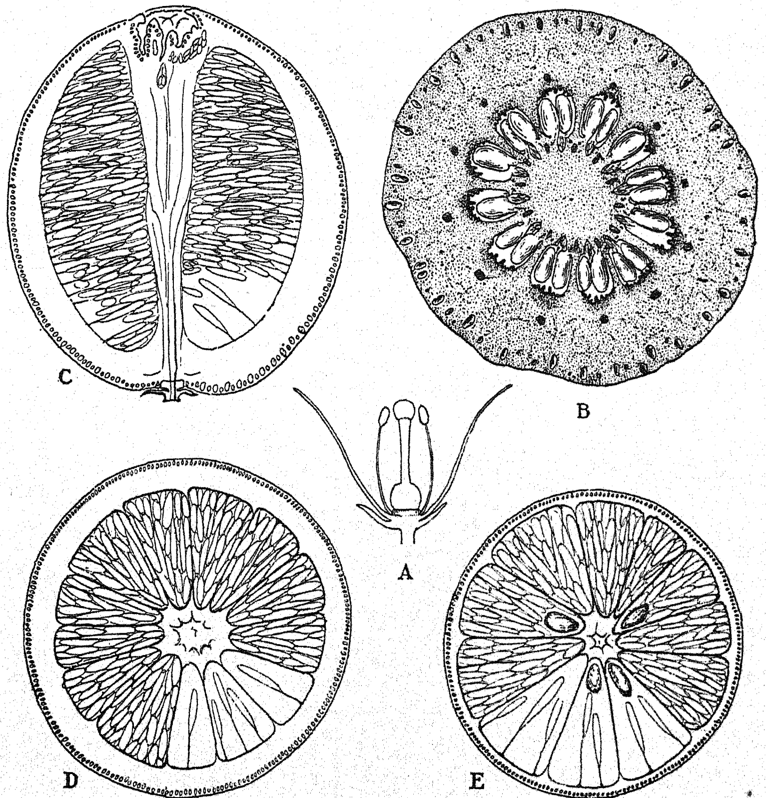


FIG. 98.—Orange: *A–D*, Navel Orange; *E*, Valencia Orange. *A*, *C*, *D*, *E*, one-half natural size; *B*, × 8. In *C*, *D* and *E*, many of the juice sacs have been omitted in the drawings. All of the juice sacs start from the inside of the rind, as shown in *B*, which also shows that the young Navel Orange has numerous seeds.

of the flower is shown in Fig. 98*A*. In the ordinary Orange the petals, stamens, style, and stigma fall off soon after pollination; in the Navel Orange fertilization rarely takes place, but the petals

and other parts fall off, just as if normal fertilization had occurred. The most striking feature of the Navel Orange is that after the ovary has begun to develop, a second ovary appears within it, near the top. The second ovary is abnormal, forming the "navel," but it does not become an edible part of the fruit (Fig. 98*C*). Just before the petals fall off, a transverse section of the ovary shows about a dozen cavities, each containing young ovules which, in the Navel Orange, do not get beyond this stage, and, consequently, the mature fruit is seedless. In other oranges the ovules develop into seeds (Fig. 98*E*).

The principal juicy part of citrous fruits consists of juice sacs. Even before the petals fall, one can see, on the outer walls of the cavities, outgrowths extending in toward the ovules. These outgrowths, which are just starting in Fig. 98*B*, develop rapidly and, in the ripe Orange, become the edible part of the fruit. In three of the chambers of Fig. 98*D* and *E*, to make the structure clear, only one, two, or three of the growing parts are shown. Each one is like a sac of juice attached to the inner wall of the carpel by a slender thread. If one remembers this structure and uses his spoon accordingly, it is possible to eat even a Grapefruit without spraying himself and his neighbors with citric acid. In the outer part of the skin of the Orange and other citrous fruits, there are numerous glands containing oils, which give to each a characteristic odor.

The Banana is an elongated berry with a skin which separates rather easily. The skin consists of receptacle. Green Bananas are as indigestible as green Apples, because the edible part consists largely of starch with some tannin, which gives a puckery taste; but, as the fruit becomes yellow, the tannin disappears and the starch changes into sugar, a change which is usually not quite complete until little brown spots begin to appear on the skin. Most Bananas are eaten before they get that ripe and, consequently, people who eat so rapidly that they swallow their food before the digestive juices of the mouth can change the starch into sugar are likely to complain that Bananas are indigestible.

The most delicious Bananas, small and thin skinned, do not get to the temperate markets, because they do not stand transportation; but, in the tropics, they are very popular.

The Drupe.—The Peach is a drupe. It is an ovary in which the inner part of the wall becomes hard and stony, while the outer part becomes fleshy and juicy.

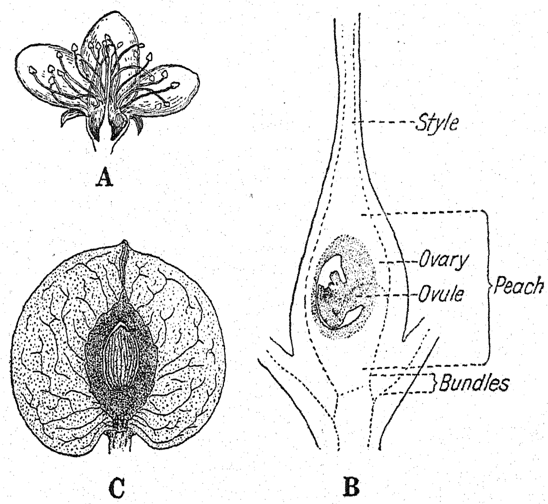


FIG. 99.—Peach: *A*, the flower natural size; *B*, longitudinal section of young flower, × 12. The shaded region will become the seed and the stone. *C*, ripe Peach, showing the seed, the stone and the edible part. One-half natural size.

FIG. 100.—Almond, showing resemblance to the Peach. Two-thirds natural size.

When the flower is in full bloom, the ovary is very small. It contains two ovules, but, usually, only one of them becomes a seed. After fertilization the ovary wall grows immensely and

gradually differentiates into the inner stony and outer fleshy layers. One of the ovules also increases greatly in size and becomes the seed, which is not very hard, and many people like to eat it. The great increase in size will be seen by comparing *A* and *C* of Fig. 99, which show the ovary, natural size, at the time of pollination and, later, when it has become a ripe Peach. In *B*, of the same figure, showing an ovary just after the petals have fallen, the shaded part is to become the seed and stone.

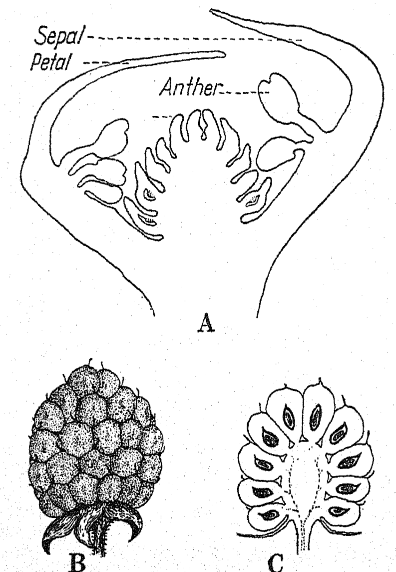


FIG. 101.—Raspberry: *A*, the flower, × 30; *B*, ripe Raspberry, natural size; *C*, longitudinal section, showing that the Raspberry is composed of many small drupes.

The Almond has a very similar structure until it reaches the final stages of development, when the outer fleshy part becomes dry and separates from the stony part like a husk. When Almonds are raised in large quantities for the market, the husk is removed by a kind of threshing machine. The edible part is the seed inside the stony layer. The appearance of the young Almond, while it still resembles a Peach, and when the outer part has become dry, and, still later, when the husk has been removed, is shown in Fig. 100.

The Apricot, Plum, and Cherry are also good examples of the drupe.

The Aggregate Fruit.—The Raspberry is an *aggregate* fruit. It consists of numerous very small drupes crowded together and belonging to a single flower. Each small drupe, or *drupelet*, is an ovary which ripens fleshy on the outside and stony within, each drupelet having one seed, so that it is like a very small Peach. A longitudinal section of the flower, somewhat enlarged, is shown in Fig. 101*A*; the ripe Raspberry, natural size, is shown in *B*, and a longitudinal section, in *C*.

The Blackberry and Loganberry are similar, but the drupelets are so firmly united to the receptacle that it breaks off with them and forms a part of the fruit, while in the Raspberry the drupelets, although sticking to each other, easily come loose from the receptacle, so that the fruit is thimble shaped. Raspberries are sometimes called Thimbleberries.

The Pome.—The Apple is a typical pome. Here also belongs the Pear, Quince, Crab Apple, Thorn Apple, and others.

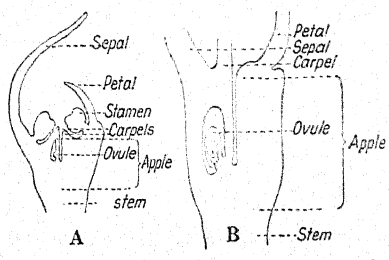


FIG. 102.—Apple. *A* and *B*, longitudinal sections showing relation between flower and fruit. *A*, the young bud; *B*, the flower about the time of pollination. × 6.

The development of the Apple from the flower is very complicated. The sepals, petals, and stamens are above the ovaries, which are usually five in number. After these floral parts have appeared, as shown in Fig. 102, the receptacle upon which they are borne begins to grow up together with ovaries,

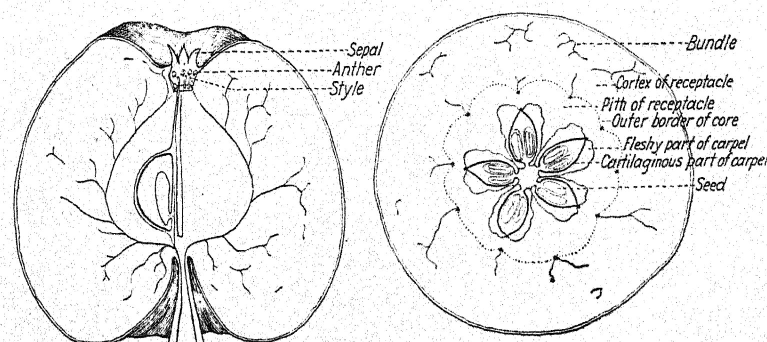


FIG. 103.—Apple. Longitudinal and cross-section. Natural size.

completely surrounding them and, finally, becoming the entire edible part of the fruit. The old statement that the edible part is a fleshy calyx was a mistake.

The stem and the calyx, corolla, and stamens are conspicuous in the young flower; but after the petals have fallen off, the calyx, stamens, and remains of the styles wither and remain

at the top, while the part between them and the stem grows immensely. This can be seen by comparing a section of a flower soon after the petals have fallen (Fig. 102*B*) with the ripe Apple (Fig. 103). In Fig. 102 the central portion, which is to become the core, is prominent; but, later, the outer part, consisting principally of the receptacle, grows more rapidly and becomes the only part we eat.

The walls of the ovaries, which in the Gooseberry and Grape become juicy and edible throughout, in the Apple are like miniature Peaches, the outer part fleshy and the inner part the thin cartilaginous pieces which get between our teeth when we bite into the core.

The Pepo.—The Pepo, very commonly called a gourd, is like a pome in which the outer part has become more or less hardened, while the inner carpel wall lacks any such hardening. The Pumpkin, Squash, Cantaloupe, Cucumber, and Watermelon are familiar examples. In some of the tropical forms, like the Calabashes, the outer part becomes so hard that small-fruited varieties are used as drinking cups, while the larger ones make good pails.

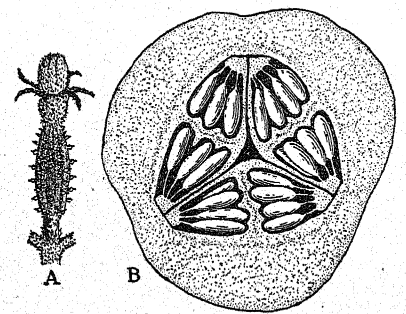


FIG. 104.—Cucumber: *A*, the female flower, natural size; *B*, slice of Cucumber as we get it on the table. Two-thirds natural size.

The Cucumber will illustrate the structure. The calyx, corolla, and stamens are borne on top of the receptacle, which is closely united with the carpels. The edible part of the Cucumber consits, therefore, of both carpels and receptacle. The seed coats are often gelatinous and, in partially matured specimens as used on the table, can be eaten with the rest of the fruit.

The relation of the mature fruit to the flower is seen in Fig. 104, where *A* shows the flower bud, natural size, just before the blossom opens, and *B* shows a section of the matured fruit as we get it on the table.

In the Watermelon the central portion is very fleshy, so that the seeds look as if they were imbedded in it; but in the Canta-

loupe most of the central part loses its fleshy character and becomes fibrous. This makes the fruit appear hollow, and the seeds are easily scraped out. Many gourds are like the Cantaloupe in this respect, and many are like the Watermelon.

The Multiple Fruit.—Some multiple fruits, like the Mulberry, look like aggregate fruits; but the aggregate fruit is developed

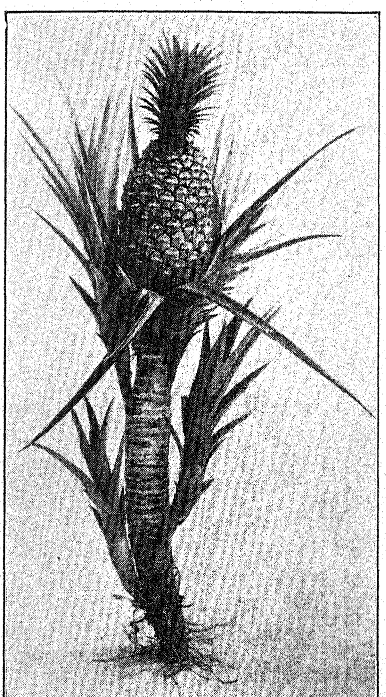


FIG. 105.—Pineapple. A complete plant with roots, stem, suckers, and fruit. (*From a negative taken in Hawaii by D. Weller.*)

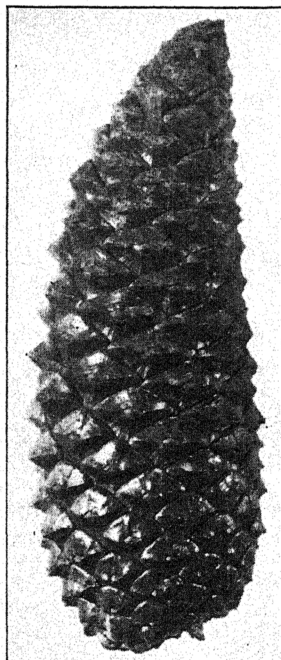


FIG. 106.—Pine cone. From a specimen picked up at the ancient villa of Cicero. Two-thirds natural size.

from a single flower, while the multiple fruit comes from a cluster of flowers. The Mulberry and the Pineapple are familiar examples of multiple fruits (Fig. 105).

In some of the wild relatives of the Pineapple, the fruits are quite separate, not at all crowded into the multiple fruit which resembles a Pine cone and so gives the Pineapple its name.

The Isle of Pines has some Pine trees, but it owes its name to its splendid Pineapples.

The largest and finest Pineapples do not reach the temperate markets, because they are not suitable for shipping long distances. In the region south of Vera Cruz in Mexico, Pineapples sometimes reach a weight of 20 pounds. In some parts of South Africa, Pineapples are so abundant that they have been sold at two for a penny.

The seed-bearing cones of the Pine, Fir, Spruce, Larch, Juniper, and many other cone-bearing trees are multiple fruits. The beautiful Pine cone shown in Fig. 106 came from Rome, Italy, and was picked up at the ancient home of Cicero, the famous orator.

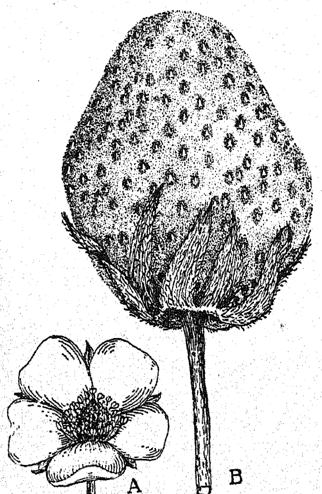


FIG. 107.—Strawberry: *A*, the flower, and *B*, the mature fruit; both natural size.

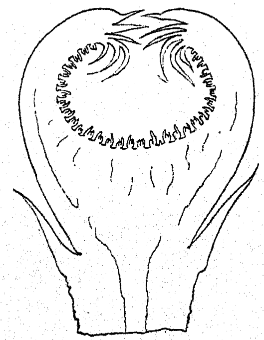
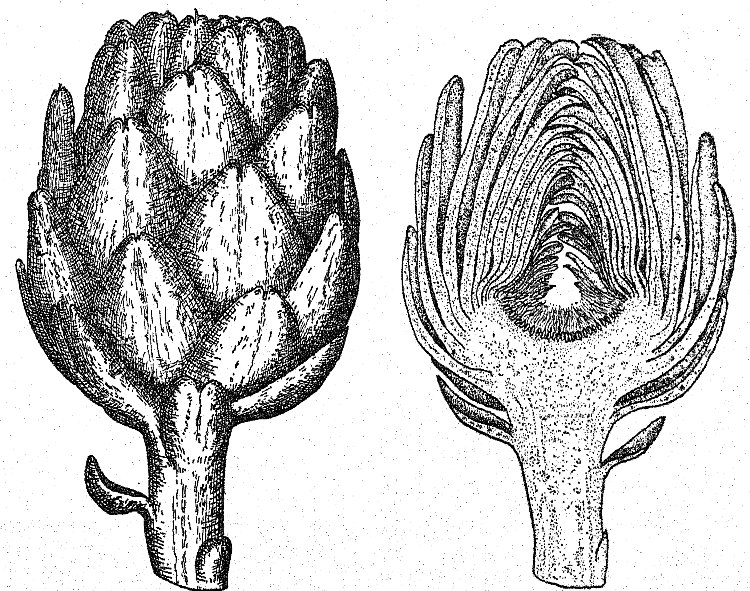


FIG. 108.—Young Fig, showing numerous flowers lining the depressed top of the flower stalk (receptacle). × 4.

Accessory Fruit.—In accessory fruits the edible part is something other than the carpels but is always associated with them. The Strawberry is our most familiar example. The petals of the flower fall off; the stamens, which are attached to the flattened part of the receptacle, dry up; the calyx and some of the bracts associated with it remain green but are picked off before the Strawberry is ready for the table. The ovaries are the little yellow dots on the surface of the ripe fruit; the juicy, edible part is the greatly enlarged end of the flower stalk, which

we call the receptacle. The relation between the flower and the fruit is shown in Fig. 107.

The Fig is an accessory fruit in which the flowers are borne on the inner surface of a cuplike branch which, on maturing, becomes sweet and pulpy. The so-called seeds are really tiny ovaries, each a part of a separate flower (Fig. 108).



A B

FIG. 109.—Artichoke: *A*, surface view, showing the large edible bracts; *B*, thick section, showing in the curved line in the center, some of the numerous flowers characteristic of the head in the Sunflower Family. One-half natural size.

The Artichoke is another accessory fruit which is gaining some popularity. It belongs to the Sunflower Family. In this case we eat the bracts which surround the flower cluster. The Artichoke is like a big Thistle head and the part we eat corresponds to the spiny bracts which surround the flower cluster of the troublesome weed. The flowers themselves are not eaten. A surface view of the fruit, as we see it on the market, is shown in Fig. 109*A*; and a section through the middle, showing the fleshy bracts and the flower cluster is seen in *B* of the same figure.

DRY FRUITS

Dry fruits are those which ripen without becoming juicy or fleshy; but they may be fleshy before ripening and some, like String Beans, are eaten in this condition. Some dry fruits, like Beans and Lilies, split open in a very regular way when ripe; and others, like the Hickory Nut, remain closed until broken by the germinating seed. A fruit, like the Bean, which splits open is called *dehiscent;* and one, like the Hickory Nut, which does not split open is called *indehiscent.*

Dehiscent Fruits.—All dehiscent fruits might go under the general name of *pods.* Most of them split lengthwise, but a few split crosswise.

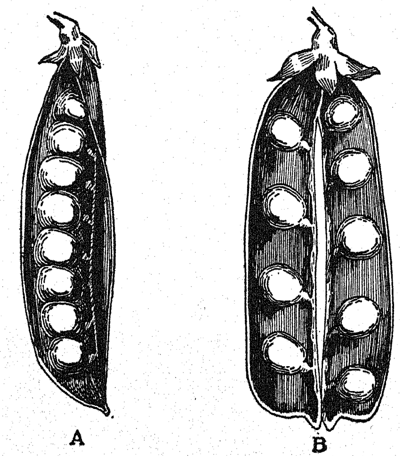


Fig. 110.—Pod of the garden Pea, a typical legume. One-half natural size. (*From a drawing by Ethel Thomas.*)

The Legume.—Peas and Beans are familiar dehiscent fruits. The pistil consists of one carpel, corresponding to a leaf, with its margins turned in and closely appressed, thus forming the ovary cavity. The peas are borne on the inturned margins (Fig. 110). If the fruit is allowed to ripen, the edges split apart (dehisce), and the ovary looks like what it really is, a leaf with a midrib and with peas on its margin.

A fruit like the Pea or Bean is called a *legume.* Clover has a very small legume and the Honey Locust has a large one. Some tropical plants have legumes looking like immense Bean pods, two or three feet in length, with sweet, juicy seeds an inch or two in diameter.

Generally, the leaves (carpels) which form pistils do not look so leaflike as in the legumes; but whether the pistil is made up of a single carpel, as in legumes, or of two carpels, as in the Shepherd's Purse, or of three, as in the Iris and Lily, or of many carpels, as in the Poppy, it is still regarded as made up of leaves.

The Capsule.—Any dehiscent pod which is made up of more than one carpel may be called a *capsule*. There are various kinds

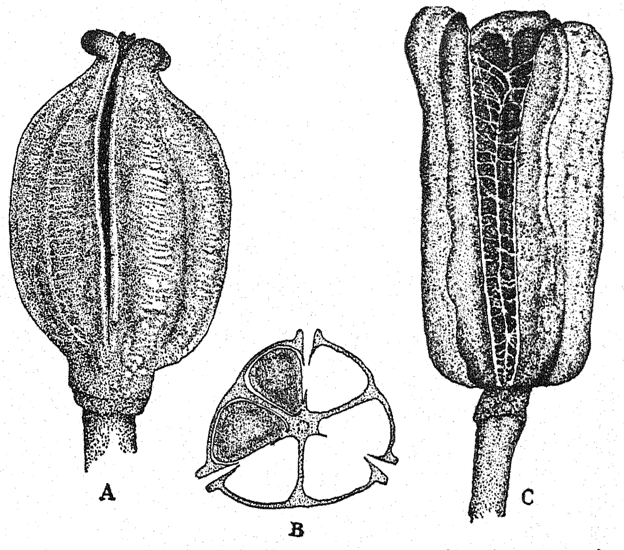


FIG. 111.—Capsule of Lily. *B*, just beginning to split; *C*, cross-section at this stage, two seeds still attached; *C*, old capsule after seeds have dropped out. Natural size.

of capsules, each with a name of its own. Most of them split lengthwise, as in the Lily (Fig. 111). The *Iris*, Jamestown Weed, Horse Chestnut, Mustard Shepherd's Purse, Violet, and many others furnish examples of the capsule.

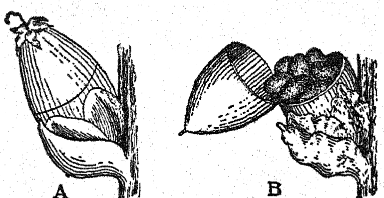


FIG. 112.—Pyxis of common Plantain. *A*, nearly mature; *B*, ripe fruit as the seeds are dropping out. × 5.

The Pyxis.—A small pod which splits crosswise is called a *pyxis*. The name means a box, and it was suggested because the top comes off like the lid of a box. The fruit of the common Plantain, which we try to keep out of the grass on our lawns, is a pyxis (Fig. 112). The Pigweed and Purslane have fruits of this sort.

Indehiscent Fruits.—Indehiscent fruits do not split open when ripe. In some the fruit decays and frees the seeds in that way;

and in others the seed breaks its way out as it swells during germination. Several kinds of indehiscent fruits have received special names, four of which—the *akene*, *grain*, *nut*, and *key*—are in common use.

The Akene.—The akene is a small, dry, one-seeded fruit, which might easily be mistaken for a seed, because the seed nearly or entirely fills the ovary cavity, and both seed and ovary harden together, making the ovary wall look like a seed coat. The Buckwheat and Buttercup are typical examples,

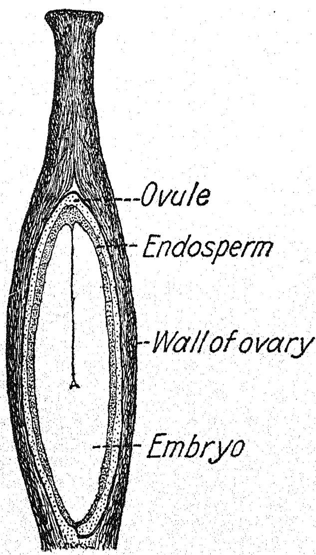


FIG. 113.—Akene of Cosmos. × 7.

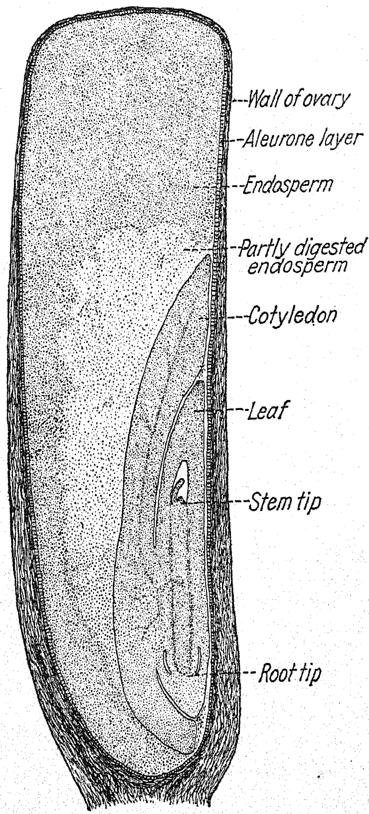


FIG. 114.—Grain of Corn. × 10.

but forms like the Dandelion and all the Sunflower Family are classed here (Fig. 113).

The Grain.—The grain is like the akene, except that the ovary wall is relatively thin and adheres so closely to the seed that they can hardly be separated. Many grasses like Wheat, Oats, Rye, Barley, Rice, and Corn are good examples Fig. 114). In

Corn, and in many others, the embryo lies at one side of the endosperm. In the ripe seed the nucellus and its integuments have been practically all absorbed, or tightly compressed, so that

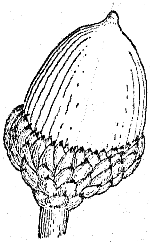


FIG. 115.—Nut (Acorn) of Oak, with cup made up of many bracts. Natural size.

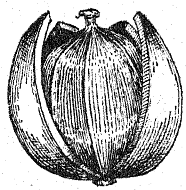


FIG. 116.—Hickory nut, with its four bracts. Two-thirds natural size. (*From a drawing by Ethel Thomas.*)

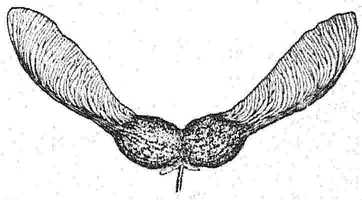


FIG. 117.—Key of Maple. Natural size.

one sees readily only the thin ovary wall, the endosperm, and the embryo.

The Nut.—The Hickory Nut, Pecan, Walnut, Hazel Nut, Chestnut, Acorn, Brazil Nut, and Coconut are familiar examples of this type of fruit. A nut has a hard shell and contains only one seed; consequently, it is like an akene, only larger. It would be difficult, or even impossible, to distinguish between a very large akene and a very small nut, because the two are often so much alike, except in size.

FIG. 118.—Key of Ash. Natural size.

The cup which surrounds the immature nut in the Acorn, Chestnut, Hazel Nut, Hickory Nut, and others is not a part of the ovary but consists of variously modified leaves or bracts just below the flower.

In the Oak the cup of the acorn is made up of a large number of scaly bracts which overlap like shingles on a roof (Fig. 115).

In the Hickory the cup is composed of four bracts which split open very regularly when the fruit is ripe (Fig. 116). The edible part, in this case, is the embryo.

In the Chestnut the cup is a spiny bur; in the Hazel Nut it is leafy; and there are other forms of cup, but all serve as a protection while the nut is young.

The Key.—The winged fruit of the Maple, Box Elder, Ash, Elm, and many others is called a *key.* It is like a nut, except that it has a border, or wing, which helps in scattering the seed (Figs. 117 and 118).

GENERAL REMARKS

The value of fruits can hardly be overestimated. Cultivation and plant breeding, even in the last 50 years, have immensely improved many of our native fruits, like Apples, Grapes, and Peaches; and similar progress has been made with tropical and semitropical fruits, like the Orange, Pineapple and Banana.

The chemical composition of fruits shows almost infinite variety, but water, starch, and sugar are present in greater abundance than any other substances.

In the Grape and Cherry about 80 per cent is water; in the Plum, Peach, Apple, and Pear, about 85 per cent; and in the Watermelon, about 95 per cent.

Starch is also abundant but does not reach such a high percentage as water, and, besides, the starch changes to sugar as the fruit ripens.

Sugar is present in the ripe fruit, often in considerable quantity. Raisins have about 56 per cent of sugar; dry Figs about 48 per cent; Grapes, 12 to 18 per cent; Cherries, 8 to 13 per cent; Apples, 6 to 8 per cent; Pears, 7 to 8 per cent; Plums, 6 per cent; Red Currants, 4.75 per cent; Peaches, 3.5 per cent; and Apricots, 1.5 per cent.

Besides, there are many chemicals in lesser quantities which give to fruits their characteristic tastes, odors, colors, and other features.

The great improvements in transportation are bringing to our groceries tropical fruits which, only a few years ago, were seen only as curiosities in the more expensive fruit stores. The Mango, Cactus, Pomegranate, Pawpaw, and many others are frequently seen in city markets.

Many diseases affect the fruit directly. You do not have to hunt for a green mold on grapes; spots develop on Beans, Apples, Tomatoes, and others; a rot often appears at the stem end of a Watermelon. Almost every fruit may have some disease which can spoil it for the table.

Since plant diseases destroy millions of dollars worth of fruit every year, much study is being devoted to prevention and cures. Some people are not hurt by Poison Ivy; and some will not take smallpox even when thoroughly exposed. We say that such persons are *immune*. Similarly, there is an individual plant, here and there, which is immune to some diseases which is fatal to its neighbors. Seeds from such a plant may produce other plants which are also immune. It is an easy and effective way to deal with some diseases to propagate only from immune plants.

In most cases, the remedy is not so simple. The study of plant diseases is becoming so highly developed that already there are specialists in diseases of trees, fruits, vegetables, and seeds. Schools for the study of plant diseases are likely to become almost as highly developed as our medical schools.

CHAPTER VI

THE SEED

The leaf, stem, and root provide the food which enables a plant to produce its flower, fruit, and seed. The seed is a part of the fruit, but generally becomes free from it sooner or later. The function of a seed is to produce a new plant.

Definition.—The ovule finally becomes a seed; and so a seed is often defined as a ripened ovule. Fertilization of the egg is almost always the cause which makes the ovule develop into a seed; and, therefore, we should begin to call the ovule a seed as soon as the egg is fertilized.

In rare cases the ovule develops into a seed without any fertilization of the egg, as in the Dandelion and Meadow Rue; but even in these rare cases the seeds originally were formed in the usual way.

Origin and Structure.—A diagram of an ovule at the time of fertilization is shown in Fig. 119. This is a very young seed. The pollen grain reached the stigma, the pollen tube grew down through the style and up into the embryo sac, where one of the two sperms from the pollen tube fertilized the egg and the other sperm started the development of the endosperm.

The ripe seed is shown in Fig. 120. The fertilized egg has grown into a young plant called the *embryo;* the endosperm has increased until it has become a mass of food material completely surrounding the embryo, and a hard protective layer, the *seed coat*, has been formed from the rest of the ovule. The seed breaks off from its stalk and in various ways escapes from the ovary, except in fruits like the akene and grain, where the ovary wall itself becomes a protective layer. The scar (*hilum*) left when the seed breaks loose is often conspicuous, as in the Buckeye, Chestnut, Acorn, and Bean.

The seed, then, has three principal parts: the embryo, which is the new plant; the endosperm, which is the food for the young

embryo during its early growth; and the seed coat, which affords protection until the seed germinates. The endosperm is often absorbed by the young embryo even before the seed germinates, as in the Bean. Seed coats may be poorly developed or entirely lacking in seeds which are to germinate immediately, as in many tropical plants. The principal thing about a seed is the embryo. All the other structures are to nourish it, protect it, or transport it to favorable places, where it may germinate and develop into a mature plant.

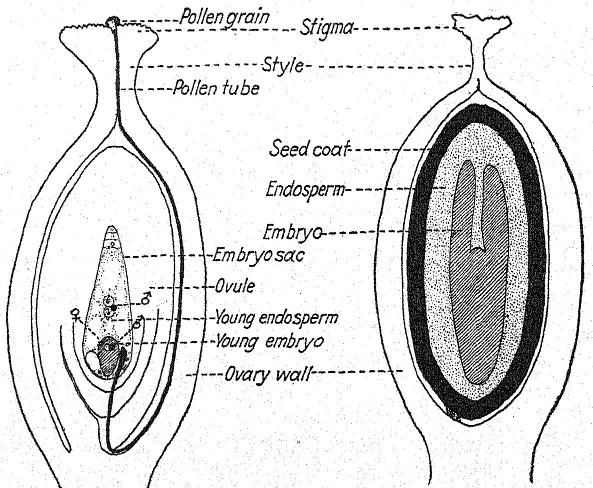


FIG. 119. FIG. 120.

FIG. 119.—Diagram of a pistil at the time of the fertilization of the egg. The two sperm muclei are marked ♂, and the fertilized egg (the first cell of the embryo is shaded with lines.

FIG. 120.—Diagram of a nearly ripe seed.

Seed Dispersal.—This means the scattering and transportation of seeds from the place where they were produced to the place where they are to germinate. Some of the most curious and interesting adaptations known in plants are those which concern the scattering, or dispersal, of seeds.

Seeds may be scattered by the plant itself, by animals, by birds, by water, by wind, or in some other way.

Seed Dispersal by the Plant Itself.—Many plants do not depend upon outside help but scatter their own seeds. If the seeds should simply fall to the ground and germinate there, the plant

would not spread very rapidly. The devices for scattering seeds to a somewhat greater distance are numerous and varied.

Ecballium is a Greek name for a plant in the Pumpkin Family, but the name is easy to remember, for the *-ball-* means *to throw*, and it gives us the ball part of our national game; the *ec-* means *out;* so the word means to *throw out.* The common name of the plant is the Squirting Cucumber (Fig. 121). The fruit is about as large as a small Cucumber, and it has a hooked stalk. As it

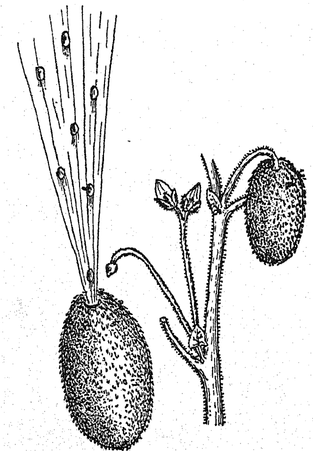


FIG. 121.—The Squirting Cucumber (*Ecballium elaterium*), showing at the right an unripe fruit, and at the left a ripe fruit just falling off and squirting out the seeds. (*After Kerner.*)

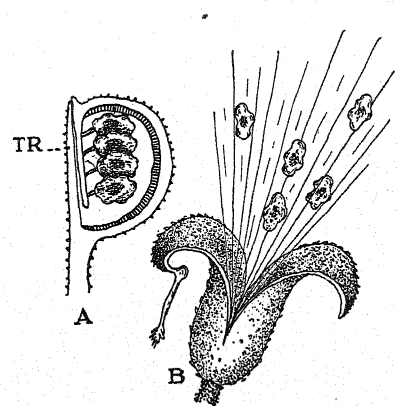


FIG. 122.—*Cyclanthera explodens.* *A*, diagrammatic section of a fruit just ready to explode; *B*, a fruit exploding and shooting out the seeds. (*After Kerner.*)

ripens, the pressure inside the fruit becomes so great that the contents are kept in only by the hooked stalk, which serves like a cork in a bottle. When the fruit starts to fall, the contents, which are liquid and semiliquid, are squirted out to a distance of several feet, carrying the seeds along. Animals, brushing against the fruits, often knock them off and become smeared with the sticky contents, so that the seeds are thus carried to much greater distances.

In another plant, *Cyclanthera explodens*, which does not seem to have any common name but has a very expressive specific name, the fruit becomes very dry. A study of Fig. 122 will

show how it scatters its seeds. The structure reminds one of the trigger and hammer of a rifle. The shaded part in *A* corresponds to the hammer spring and *tr* is the trigger. As the tension becomes too great the fruit bursts open so violently that it is entitled to its specific name, *explodens*.

The common wild *Geranium* scatters its seeds by a sudden springlike movement (Fig. 123). Each of the five seeds is thrown as if from a tiny sling.

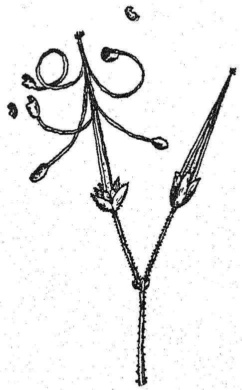


Fig. 123.—Cranesbill (*Geranium*) scattering its seeds. About natural size.

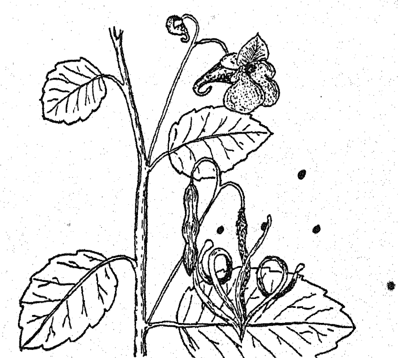


Fig. 124.—Touch-me-not scattering its seeds. Two-thirds natural size.

The Touch-me-not scatters its seeds in a somewhat similar way (Fig. 124). When the little pods have become swollen, the slightest touch causes them to burst and throw the seeds to a considerable distance.

None of the methods just described scatters the seeds very far, 2 or 3 to 50 feet being the limit.

Seed Dispersal by Animals.—Most plants depend upon outside help for scattering their seeds, many being scattered by animals and birds. The seeds and fruits eaten by animals and birds are generally destroyed by digestion in the alimentary canal; but some, like seeds in the drupelets of the Raspberry, Blackberry, and similar plants pass through uninjured and will germinate. Seeds which escape digestion may be carried far, especially by swift birds. Seeds of water plants stick to the feet and feathers

of aquatic birds, like ducks and geese, and so are carried from one pond or lake to another. Small sticky seeds may cling to the feet of migratory birds and thus be carried hundreds of miles. Although most birds keep themselves very clean, many of them become careless when the time comes to fly south for the winter or to fly back for the summer.

Many seeds and fruits are provided with hooks, or spines, or recurved hairs which enable them to stick to the fur of animals and also to the clothes of people. Such seeds may be carried great distances.

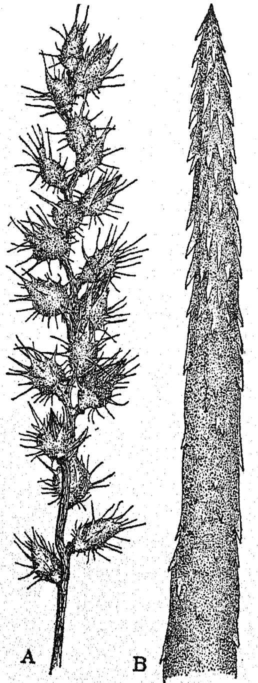


FIG. 125.—Sand Bur. *A*, raceme with burs, a little more than natural size; *B*, one of the spines, × 300, showing why it goes in easily, but will not come out.

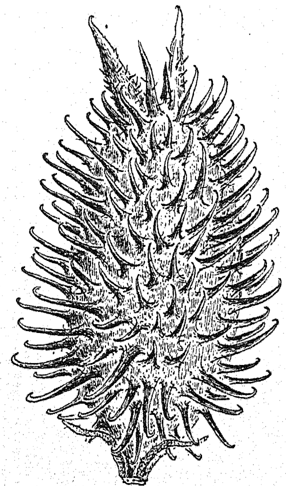


FIG. 126.—Cocklebur (*Xanthium*). Ripe fruit showing the hooks. × 2½.

A very common and very distressing plant is the Sand Bur, called *Cenchrus tribuloides* by the botanist on account of the tribulation caused by the burs (Fig. 125). They stick to one's clothes, and, when one tries to pick them off, they stick to the fingers. The burs look spiny and wicked even to the naked eye,

but, with a pocket lens, one can see that each spine is covered with smaller spines hooked backward like the barb of a fishhook, so that the spine easily goes farther in but does not come out. When the bur sticks in an animal's wool or fur, it may remain for days before it is torn loose, and so may be dropped miles from the place where it started.

The Cockle Bur is almost as bad for animals but is not so hard to remove from one's clothing. The spines are stout and recurved (Fig. 126). The Burdock is one of the worst when it sticks to one's clothes or the fur of an animal.

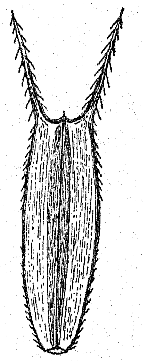


Fig. 127.—Spanish Needle (*Bidens*). A ripe akene. × 3.

The Spanish Needle, a troublesome weed, has akenes which look like seeds. One of the commonest forms of it has akenes with two needle-like spines at the top, each spine with barbs turned backward, so that it keeps going in but will not come out (Fig. 127).

The Tick Trefoil has a jointed pod, like a small Bean pod, but covered with hooked prickles which make it stick fast to one's clothes or to the fur of an animal (Fig. 128).

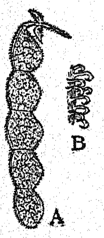


Fig. 128.—Tick Trefoil (*Desmodium*) *A*, the legume, natural size; *B*, a small portion of the border, × 20, showing the hooks.

Some of the grasses have fruits with a long bristle which is often twisted so that the name Devil's Cork Screw seems appropriate (Fig. 129). The grass shown in this figure has also been called Porcupine Grass. Since the point of the fruit is as sharp as a needle, it easily pricks into anything, and the end of the bristle, which is long and sticks out at an angle with the main axis, brushes against one thing and another, making the fruit turn round and round, so that it bores in farther and farther. In some parts of Australia sheep raising had to be abandoned on account of losses due to these fruits, because they got into the feet causing such pain that the sheep could not walk around to get food and so died of starvation; and in other parts of the body they caused great distress, piercing through the skin into the flesh and, sometimes, even reaching the heart and killing the animal in that way.

Squirrels and other animals hide nuts and other seeds for winter eating, often covering them in the ground. If the squirrel should be killed or should forget some hiding place, the seeds germinate as well as if people had planted them.

Seed Dispersal by Wind.—The wind is very effective in scattering seeds. In some cases the entire plant is blown from one place

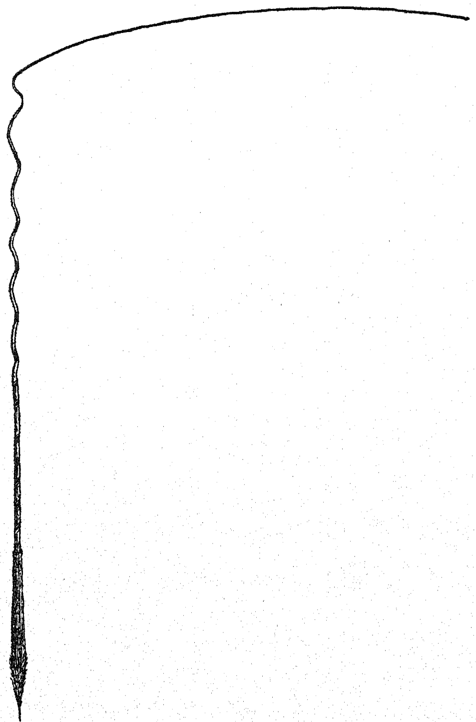


FIG. 129.—The Devil's Cork Screw. An akene, natural size.

to another; in some cases the fruit is transported; and in many cases only the seed is carried away.

Tumble Weeds have rather weak roots, so that they are easily blown loose from the ground and are bounced along for miles, dropping seeds all the way. In 1895 the Russian Thistle was a curiosity in the Middle West and was not known in the Pacific states; but now it is one of the worst weeds of every state in our country, and nearly every state has laws against letting it go to

seed. No plant has ever become established all over the country in a shorter time.

The fruit of the Maple, Box Elder, Ash, and many others is provided with a wing which enables it to sail for a short distance before it touches the ground (Figs. 117, 118). In the Basswood, the Hop Tree, *Catalpa*, Pine, and many others the *seed* has a wing which enables it to sail for some distance from the tree (Figs. 130, 131).

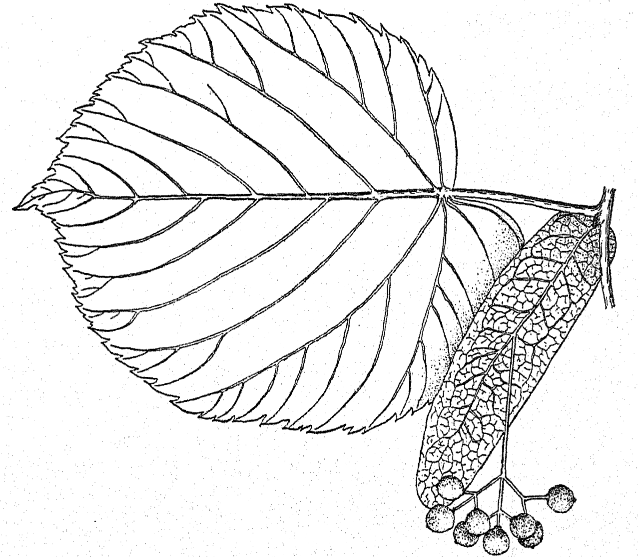


Fig. 130.—Basswood, showing a foliage leaf and a modified leaf which helps to scatter the seeds. One-half natural size.

The akene of the Thistle and Dandelion has a fluffy crown of hairs which float it as if it were hanging from a parachute (Fig. 132).

In the Willow, Poplar, Milkweed, Cotton, and hundreds of others the seeds have long hairs which float them to great distances. The Cottonwood Poplar gets its name from these cottony floating seeds which sometimes fill the air so that it looks like a snowstorm in summer. Such seeds, falling on water, float for miles (Fig. 133).

Very small light seeds may float in the air for hours before they come down. Such seeds are generally flat and may have a

wing or border, and the heaviest part of the seed is so placed that the seed will not fall edgewise but will fall as slowly as possible. It would be hard to prove just how far these small seeds can be carried by the wind, but it is probable that the distance may be many miles. So, in one way or another, seeds are scattered, sometimes falling almost underneath the plant which produced them and sometimes being carried hundreds of miles.

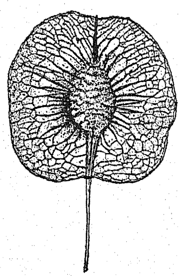


FIG. 131.—Hop Tree (*Ptelea trifoliata*). Fruit with the winged border which helps to scatter the seeds. Natural size.

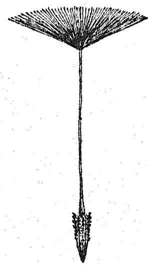


FIG. 132.—Dandelion. Akene with long beak and spreading hairs at the top which enables it to float. × 2.

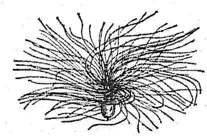


FIG. 133.—Poplar. Ripe seed with cottony hairs, which enable it to float in the air or on the water. × 2.

Longevity of Seeds.—How long can a seed live? Some seeds begin to grow as soon as they fall from the parent plant; many ripen in the autumn and germinate the next spring; and others may live for many years and still be able to germinate when conditions become favorable.

The seeds of the Willow die unless they germinate within a few days after falling from the tree. Seeds of many troublesome weeds can germinate as soon as they fall. The seeds of some members of the Pea Family may germinate after resting for a hundred years. Seeds of the Indian Lotus, believed to be more than 700 years old, have been germinated. But the length of life of most seeds is between these extremes and, generally, is only a year or two, or a few years.

Tales of the germination of wheat taken from Egyptian tombs are entirely unfounded. The story originated when a German

professor planted some mummy wheat and his young son and daughter, noticing how anxiously their father watched for it to come up, slipped in some fresh seeds because they did not want him to be disappointed. The professor, believing the mummy wheat had germinated, wrote an account of it; but, years later, when the children grew up and told him the truth, the story had become established and many people have not seen the correction.

Germination of the Seed.—The principal thing in a seed is the embryo which is to grow into a new plant like the parent. The embryo may be surrounded by the foodstuff called endosperm; or the endosperm may have been absorbed already by the embryo, as in the Bean. Surrounding and protecting the embryo and endosperm is the seed coat (Fig. 120).

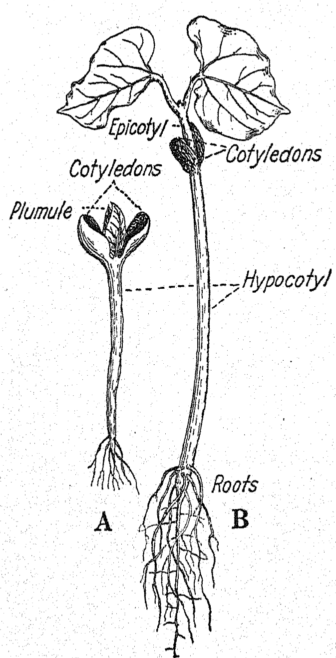


FIG. 134.—Bean seedlings. *A*, young seedling with plumule and vigorous cotyledons; *B*, older seedlings with cotyledons drying up. One-half natural size.

When the seed is ready for germination, the addition of water makes the embryo begin to swell and it soon bursts the seed coat. As it breaks out, the root turns down and the stem grows up. The parts of the young *seedling*, as the new plant is called, are the *root*, *cotyledons*, *stem*, and *leaves* (Fig. 134). Thecotyledons usually break out from the seed and become green and more or less leaflike; but they are usually quite different from the foliage leaves (Figs. 134, 135). In many cases, as in the Oak (Fig. 136), the cotyledons stay inside the seed, absorb the endosperm, and pass it on to the rest of the seedling. The tip of the seedling with the first leaf or two is called the *plumule*. The part between the cotyledon and the root is called the *hypocotyl;* and the part above the cotyledon is called the *epicotyl*.

Plants above the cone-bearing trees (Gymnosperms) are divided into two groups—the *Dicotyls,* whose seedlings have two cotyledons, and the *Monocotyls,* whose seedlings have only one cotyledon. We have already noted that the Dicotyls generally have netted-veined leaves and that a section of their stem shows a pith surrounded by a zone of wood; while the Monocotyls usually have parallel-veined leaves and have scattered bundles in the stem. In the grasses, like Corn, Wheat, Oats, Rice,

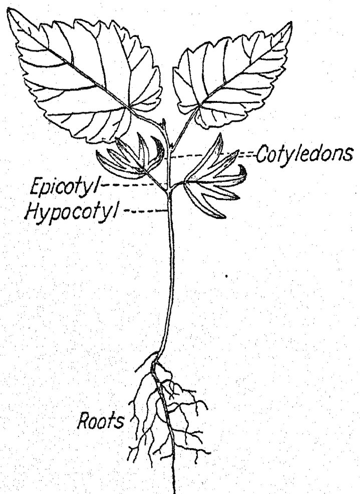


FIG. 135.—Basswood seedling, showing cotyledons very different from the foliage leaves. One-half natural size.

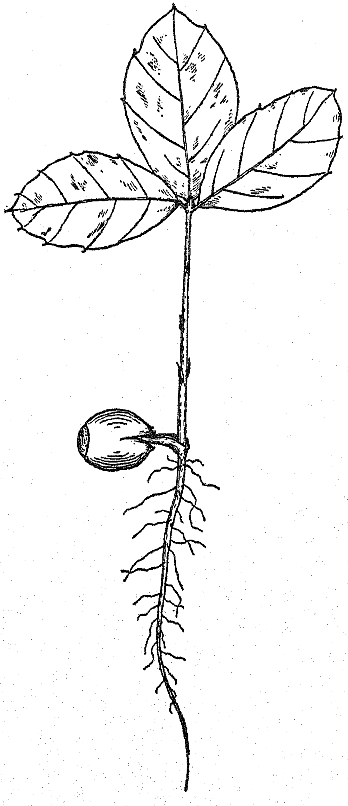


FIG. 136.—Oak. Acorn germinating. The ends of the cotyledons remain inside. One-half natural size.

Blue Grass, Timothy, etc., the single cotyledon stays in the seed, absorbs the endosperm, and passes it on to the rest of the seedling. In such cases the first green structure to appear is not the cotyledon but a real leaf.

It is impossible to apply the names, embryo, seedling, and young plant, any more definitely than we use the names, baby, child, boy,

and young man; but, in both cases, the names are useful and we know what we mean by them.

A scientific selection of good seed has made great improvements in Corn, Wheat, and other crops. Equal care has been taken with decorative plants; so that one can generally raise finer flowers from seed bought at some reliable seed store than he is likely to get by saving his own seed. The U. S. Department of Agriculture and many seed companies have expert seed testers, and, consequently, the seeds they send out are likely to germinate and produce good plants. Every spring, humorists writing for the funny columns of the papers, take their fling at the optimism of people who look at the beautiful pictures in seed catalogues and order their packets; but most of the failures to make the results equal the pictures are not due to the seeds but to the wrong kind of soil, improper fertilizers, improper watering, or other things which could be avoided by consulting some good book.

Even when the seeds are good, they do not all produce new plants. Suppose that the common garden Sunflower produces only a quart of seeds and—to make a low estimate—suppose that the quart contains 2,000 seeds. If they all grew, the next crop would be 2,000 quarts, or 4,000,000 seeds. The third year there would be 4,000,000 quarts, with 8,000,000,000 seeds. Figuring it this way, within 20 years Sunflowers would not only cover the whole world but also would be heaped up mountain high on the rotted remains of their ancestors.

One could figure the same way with Wheat, Corn, Pumpkins, and Watermelons. Each would cover the whole world in a short time. Why do they not do it?

The Sunflower could not grow very far north on account of the cold; and, in the Southern Hemisphere, they could not grow very far south. They cannot grow where it is too wet or too dry: birds eat millions of the seeds; in many places, other plants can grow better and choke the Sunflowers out; many seeds fall where they cannot grow. For one reason and another, nearly all the seeds fail to germinate, and most of those which do germinate die in infancy; although, when planted and cared for, nearly all are capable of growing into new plants.

Among plants, as among animals, there is a constant struggle for existence, and, if left to themselves, it is usually those which

are strongest and best suited to their surroundings that survive. If one is staying for a few years in the same neighborhood, it is interesting to map the individual plants growing on some small piece of ground, perhaps 20 feet square, and then make a similar map the second and third years. The three maps will be different, and, if one tries to find out the reasons for the differences, one will learn a great deal about the relation of plants to their surroundings. Such studies are an important part of the subject matter of that phase of botany which is called ecology.

CHAPTER VII

VARIOUS IMPORTANT TOPICS

Under this chapter heading we are to consider several topics so important that books have been written about each one of them; but, even in our limited space, we can get an introduction to these subjects.

Vegetative Propagation.—In addition to the usual propagation by seeds, there are various other ways in which plants are multiplied. Some of our most important economic plants, like the Apple, Orange, and Potato, are almost never reproduced from seed. The principal methods of vegetative propagation will be mentioned; but before trying any of these methods it would be worth while to consult the "Cyclopedia of Horticulture," by L. H. Bailey, a work which should be in every library.

The Rhizome.—The type of underground stem called a rhizome is often broken up into pieces, each one of which may become an independent plant (Figs. 33, 34). Some Grasses, like the Couch Grass, spread rapidly by the breaking up of the rhizome. Roses, Peppermint, Canada Thistle, and hosts of others propagate in this way. Many rhizomes, when injured or broken apart, only spread the plant more rapidly. In New Zealand the Bracken Fern is one of the worst weeds, because it covers the ground so completely that it must be removed before there can be any cultivation, and grubbing it out may only break the rhizomes and produce more plants.

The Stolon.—The *stolon* is a branch which curves over until it reaches the ground and strikes root. When connection with the parent plant is severed, the stolon becomes an independent plant. The Gooseberry, Currant, Raspberry, Grape, White Clover, and many others often reproduce in this way. Branches may be bent over and covered with soil and, when they strike root, can be cut off from the parent plant. They can be made to strike root more promptly by cutting notches into the bark of the part to be covered.

The Runner.—The *runner* is a slender leafless stolon lying on the ground. The Strawberry is our most familiar example. During the summer a single plant will produce many runners, each of which, where it strikes root, produces a new plant. In winter, the runners die and leave the new plants independent.

The Sucker.—A branch which comes from the parent stem under ground, strikes root, and then comes above ground as a leafy stem, is called a *sucker.* The Raspberry, Rose, Pineapple, Corn, and Century Plant are good illustrations. The stolon, runner, and sucker may all appear on the same plant at the same time (Fig. 137).

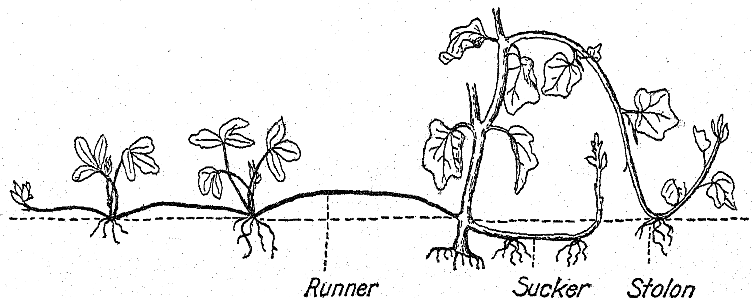


FIG. 137.—Grape, showing runners, a sucker, and a stolon on the same plant. (*After Asa Gray.*)

Cuttings.—Many plants can be cut into pieces and new ones developed from the pieces. Roots, rhizomes, stems, and leaves may be cut into pieces and used in this way; even chips of trees have been known to produce new plants. Tips or side branches, with three to six leaves, can be cut from vigorous plants of *Geranium, Coleus,* or similar plants and inserted about an inch in the soil, where they soon develop roots and become established. Small pieces of Cactus stem may be used in the same way.

Most Begonias are easily propagated by cutting leaves into several parts and putting the pieces edgewise into moist sand or soil.

Probably no plant can be propagated more readily from the leaf than *Bryophyllum.* When a leaf falls to the ground, a new plant may bud out from every notch in the margin of the leaf (Fig. 138). New plants are often formed in the notches while the leaf is still on the plant. Some ferns reproduce in this way.

The "eyes" of the Potato are buds which grow into new plants, when the Potato is cut into pieces and planted.

The Screw Pine produces buds on the stem near the base of the plant. When they have developed several leaves and a couple of roots, they may be cut loose and potted.

Cycads, among which the Sago Palm, whose dark green leathery leaves are so much used on Palm Sunday and for funeral wreaths, is best known, are propagated commercially by cutting notches into the cortex. Buds develop in the wound and, when they reach a desirable size, are removed and potted.

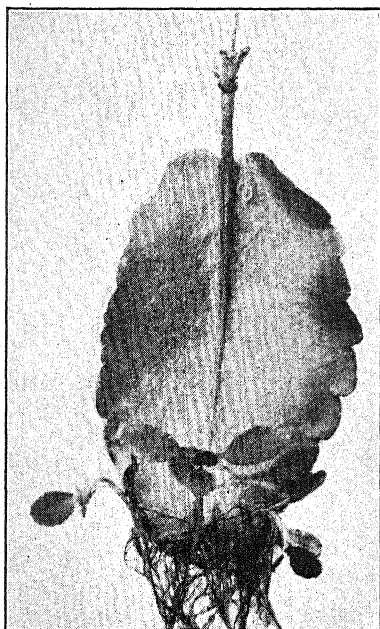


FIG. 138.—*Bryophyllum*. A leaf with new plants growing out from notches in the margin. One-half natural size.

The leafy top of a Pineapple, as you get it at the grocery, readily grows into a new plant. Cut it off and let it dry for several days; then stick the cut end into the soil.

If the top of a *Yucca* be cut off, it will grow in the same way, and a new crown of leaves will form on the part remaining in the ground.

The top of an India Rubber Plant, or the tip of one of its branches, might not grow if stuck into the ground in this way; but if a cut is made about a foot from the tip of the plant or one of its branches, and the wound is bound up with moss and kept moist, roots will form. The stem or branch can then be cut off just below the moss and potted. Figure 61 shows how this is done.

Budding.—Budding is an extremely important method of propagation especially in citrous fruits, like the Orange, Lemon, and Grapefruit; and in Peaches, Cherries, Plums, and Roses. Most fruit trees and Roses can be propagated in this way.

Budding consists in putting a single strong bud under the bark of another plant. It is best done in the spring or autumn, when the bark is loose, and usually succeeds best with young plants about a year old; but it is often done with plants six or seven years old. The operation is not difficult. Make a T-shaped cut just through the bark of the *stock*, as they call the piece which is to receive the bud. Make the top of the T first, then the longitudinal cut, and, as you finish the longitudinal cut, press the bark to each side so as to loosen it a little (Fig. 139*A*). From the plant which you wish to propagate, cut out an oval piece contain-

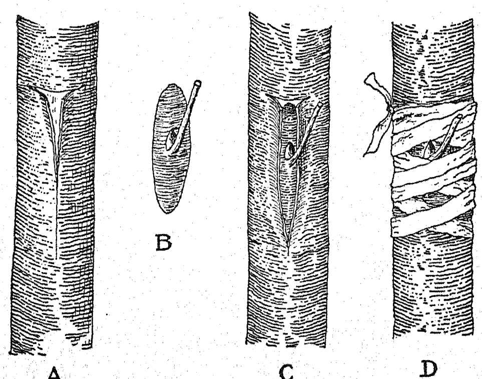


FIG. 139.—Budding. *A*, the T-shaped cut; *B*, a small piece with the bud; *C*, the bud pushed into place; *D*, the bud securely tied. (*After Bailey.*)

ing a bud in the axil of its leaf (Fig. 139*B*). This is best done by placing the thumb beneath the bud and making a quick downward stroke. Just under the bud, cut a little into the wood. This wood may be removed, but it is not necessary. Slip the bud down into the cut and tie it in place with a soft string (Fig. 139*C*, *D*).

Grafting.—Grafting may be defined as inserting a twig, called a *cion*, into a stock. The Apple, Pear, Quince, Peach, Cherry, Plum, and Rose are commonly propagated in this way.

There are various methods of grafting, one of which is shown in Fig. 140*A*, *B*, *C*).

Many herbaceous plants, like the *Geranium*, *Chrysanthemum*, and Cactus, can be grafted. More than 50 varieties of Chrysanthemum have been grafted upon a single plant.

By grafting, a vigorous tree with poor fruit can be made to produce excellent fruit, for the cion preserves the character of the fruit of the tree from which it came, while seeds of an excellent Apple, Peach, Quince, or Cherry may produce trees with very inferior fruit. Several varieties of Apple can be made to grow upon the same tree. Oranges, Lemons, Grapefruit and Tangerines, by grafting, may be made to grow upon the same tree. In *Ginkgo*, the Maiden Hair Tree, which is becoming so popular, a cion from a female tree can be grafted upon a male tree and thus a dioecious tree can be made monoecious.

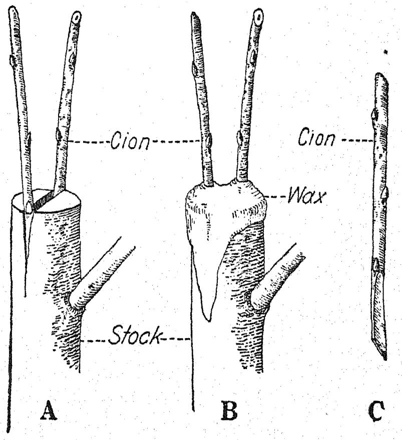


FIG. 140 —Grafting. *A*, the stock cut and the cions in place; *B*, after covering with wax; *C*, the cion, showing how it should be cut.

Here again that "Cyclopedia of Horticulture" will be useful, for the operations of grafting are described in detail and the time of year, size of cion, kind of wax, and other data are given so definitely that you can make grafts with very fair prospects of success.

Advantages of Vegetative Propagation.—A seed of a Rose, an Apple, a Strawberry, a Grape, or a Potato will produce another Rose, Apple, Strawberry, Grape, or Potato plant; but the plant may not be nearly so good as the parent. A hundred seeds from a Strawberry may produce a hundred Strawberry plants, but among them there may be one plant which produces exceptionally fine berries. Seeds from these fine berries may produce plants with very poor berries; but runners from the plant with fine berries will produce new plants with the same kind of fine berries. A plant may produce four or five runners, each developing a new plant; next season, the original plant and the new plants may have five runners apiece; so that in a few years there will be thousands of plants, all derived from the one original plant with fine berries. And, in time, all the country and foreign

countries will have the fine Strawberries, all of which came from that one fine plant.

Many of our most important plants behave in the same way. Years ago, some one found a particularly fine Potato. This Potato was cut into pieces and the pieces were planted. A new plant came from each bud (eye) of each piece, and these plants produced fine Potatoes like the original. And now, all over the world, there are Early Rose Potatoes, all of which have come from that Potato which some one found and propagated. Seeds from any Early Rose Potato are likely to produce inferior plants.

Grafting and budding, or any other form of vegetative reproduction, preserve the quality of the original, for the new shoot is really a part of the plant from which it came.

People who are trying to get finer fruits plant immense numbers of seeds, and, when they find a plant which is valuable, they propagate it by grafting, budding, cuttings, runners, or some other vegetative method.

Valuable plants, obtained by crossing, often produce no seed which will germinate; but they can be multiplied by some form of vegetative reproduction. Where students have an opportunity, real knowledge can be gained by experimenting with common plants.

Weeds.—What is a weed? The Marguerite is a *Chrysanthemum.* It makes a beautiful display and is often on sale at the florists; but on the farm, where it is only the White Daisy, it is a despised weed. In many places the Bracken Fern is cultivated as a beautiful decorative feature of the lawn; but in New Zealand, where it sometimes reaches a height of 20 feet and covers the ground almost to the exclusion of other plants, it is a troublesome weed. The Blackberry, which often grows wild, is a desirable plant if it is growing in waste places; but if it is growing where one wants to cultivate the ground, it is a weed. No matter how beautiful a plant may be, if it interferes with cultivation or grows where it is not wanted, it becomes a weed.

Many plants, like the Thistle, Poison Ivy, the Plantain and Dandelion on our lawns, Ragweed, Pigweed, Couch Grass, Russian Thistle, Burdock, and many more, are so bad that most states have passed laws against them; but they grow just the same.

Weeds generally produce abundant seed which may live for years. They are effective in scattering their seeds, having all kinds of hooks and spines for clinging to animals. Some seeds are carried by the wind, and Tumble Weeds may be blown for miles, dropping seeds at every shock. Their seeds germinate readily and any one who has a garden knows that weeds grow rapidly.

Many weeds are injurious to animals, some because their seeds cause irritation or ulcers; and some because they are poisonous, causing "loco" diseases, as in our western states, or "rickets," as in some parts of Australia.

Some weeds, like Ragweed and Goldenrod, cause hay fever by their pollen, which is often blown to great distances by the wind.

It is hard to get rid of weeds. Pulling them up, grubbing them out and hoeing are effective but distasteful remedies. Birds eat immense quantities of weed seeds. The U. S. Department of Agriculture has excellent bulletins on the control and eradication of weeds.

Classification.—A hundred years ago, botany was little more than the naming of plants; fifty years ago, students of botany devoted most of their time to classification; and even today most people think a person is a botanist if he knows the names of a lot of plants. A botanist should know the names of a great many plants, but he should also know something of their structure, physiology, ecology, propagation, uses, and diseases.

In classifying plants the principal divisions are the *species*, *genus*, and the *family*.

The seeds of the garden Sunflower produce more garden Sunflowers like the parent. They all belong to the same *species*. All the seeds of the Sugar Maple produce more Sugar Maple trees; they are all of the same species. All the seeds of the Red Maple produce only more Red Maple trees; and the seeds of the Soft Maple produce Soft Maples. These three kinds of Maples are three species of Maple (Fig. 3).

Species which are so much alike constitute a *genus*. In these cases, Sugar, Red, and Soft are the species names, and Maple is the genus name. In the Oaks, Red Oak, White Oak, Black Oak, Swamp Oak, and Live Oak are different species of Oak (Fig. 4).

The scientific names of plants are written in Latin, the genus name coming first, followed by the species name. The Latin genus name for Maple is *Acer;* so we have *Acer saccharum* for Sugar Maple, *Acer rubrum* for Red Maple and *Acer saccharinum* for Soft Maple.

The genus name and the species name constitute the name of the plant; so that *Acer rubrum* is the scientific name of the tree, just as Red Maple is its common name.

The advantage of the scientific name is that it is the same in all languages, like the Arabic numerals, 1, 2, 3, 4, and musical notation. The Englishman, Frenchman, German, Russian, Arabian, and Japanese can play from the same sheet of piano music; and, in the same way, botanists of all nationalities know the scientific names of plants.

Genera which resemble each other are grouped into *families*, just as species which resemble each other are grouped into genera. The Pumpkin, Watermelon, and Cucumber are some of the genera which make up the Pumpkin Family; and the Apple, Quince, Peach, Cherry, Raspberry, Strawberry, and Rose are some of the genera of the Rose Family.

Families which resemble each other are grouped together in an *order;* and orders which resemble each other are placed in still larger groups.

There are books, called *manuals*, which will enable you to name most of the flowering plants of your vicinity, if you have studied this book up to this point.

Morphology.—The name means the science of forms. The external form and internal structure of plants is a large part of the subject matter of morphology; but it also deals with relationships.

Of course, if the definition of species which we have just given were strictly correct, there would be no relationship between the Sugar Maple and the Red Maple. They would have been Sugar Maples and Red Maples from the beginning and would never be anything else. But a thousand seeds from the Evening Primrose do not produce a thousand plants exactly like the parent. Some are a little different, and a few may be so different that they would be described as different species, if we did not know that all the seeds came from the same plant. Such differences may be permanent, and thus new species may arise. Not only species, but

genera, families, and even larger groups may be related to each other. One of the most difficult and interesting problems of morphology is the tracing of relationships.

Ecology.—Ever since people noticed plants at all, they doubtless noticed that some plants, like the Cat Tail and Water Lily, always grow in wet places; while others, like the Cactus and Century Plant, grow in dry places; and still others, like the Maple and Hickory, grow in places which are neither so wet nor so dry.

Ecology treats of plants in relation to their surroundings. At first, classifying plants as water plants (Hydrophytes), and dry plants (Xerophytes), and plants growing in conditions between the wet and the dry (Mesophytes) constituted a large part of the subject.

Plants were grouped into various associations. Then the subject became more complex. It was noticed that there was often a more or less definite succession of different kinds of plants as one goes from one set of conditions to another. The reasons for the succession have been found out in many cases. A forest of one kind of tree may not be able to continue itself, because its seedlings cannot grow in its own shade; while the seedlings of other trees which can grow in the shade gradually come and displace the original forest.

Much attention has been given to the effect of conditions upon the structure of leaves, stems, roots, and other parts of the plant. Seeds of the Hackberry tree, planted on a river bank, may grow into large trees; but, planted on a sand dune, they produce only small shrubs. The microscopic structure is just as profoundly affected as the external form.

Ecology is becoming so highly developed that it is important economically, and many are making this field of botany their profession. To become a good ecologist, one must know the morphology and physiology of plants and must have a thorough knowledge of classification.

Physiology.—Plant physiology deals with the life of the plant, how it grows, how it gets its crude food materials and manufactures them into usable foods, and how it reacts to light, heat, moisture, and other things. The experiments showing that oxygen is given off by green plants in sunlight, that water is

given off by leaves, that starch is formed, that liquids move up in the woody part of the plant, and that most of the downward movement is in the bark—all these and others are experiments in plant physiology. It is as necessary for a plant physiologist to know the structure of plants as it is for a physician to know the structure of the human body.

Forestry.—In our country forestry is a rather recent botanical subject, but it is needed and is growing. In a new country lumbering is likely to be wasteful and no provision is likely to be made for the future. Trees are cut down and nothing is done to provide for trees 50 or 100 years in the future. White Pine has become so scarce that it is a very expensive wood. Oak has almost disappeared from regions where it was once abundant. The giant Sequoias of California might have become extinct, if the government had not made state and national parks where these great trees are protected.

In Europe where trees began to be cut hundreds of years before America was discovered, they were forced to replace the forests or not have any wood. So they began to plant trees, and now new trees are growing to take the place of older trees as fast as they are cut down. New Zealand and South Africa are planting immense forests, which, in 40 or 50 years, will be valuable for lumber.

In the United States methods of lumbering are not quite so wasteful as they were 25 years ago. Tree planting is progressing and, in some places, is becoming effective. Forest rangers are keeping down the damage done by forest fires and many are learning things about trees which will be valuable as the planting of trees progresses.

The microscopic structure of wood, its strength, elasticity, its resistance to fire and to decay, and its suitability for various uses, belong to the subject of forestry.

Trees have their diseases, many of which are caused by fungi, like Mushrooms, Toadstools, and Bracket Fungi. Much less is known about preventing diseases of trees than is known about preventing diseases of fruits and vegetables.

Plant Breeding.—This subject has probably been studied, more or less, nearly as long as animal breeding. For a longer time than can be learned from any records, farmers have doubt-

less selected seeds from the best plants; but the subject has now been established upon a much more scientific basis. While breeders are on the lookout for such desirable varieties as may turn up of themselves, they are doing much more by systematic breeding. If a form with hardy stem and leaves has poor fruit, while another has fine fruit but poor stem and leaves, a combination of fine fruit and good stem and leaves can sometimes be secured by crossing the two kinds. The pollen of one is used to pollinate the other, and thus a combination of desirable characters may sometimes be obtained.

Wheat, fruit, and vegetables have been developed which are suited to northern, middle, or southern Sweden, while none of these would do so well in other parts of the country. In the past 30 years of scientific plant breeding, Corn, Alfalfa, and other plants have been improved more than in all the preceding years of haphazard planting. Plants suited to one part of the country or another are being developed and improved. Many plant breeders call themselves *geneticists*.

Plant Diseases.—Plants are very susceptible to diseases, some of which are caused by animals, especially by insects, and many of which are caused by other plants, like Bacteria and Fungi. The broad sticky band, daubed around trees a few feet from the ground, is to prevent insects from crawling up. Spraying is done to kill insects and small disease-producing plants.

A white mold appears on bread and a green mold forms on cheese, if they are exposed to the air. Grapes and Cherries get moldy; Apples and Potatoes rot; a Rust gets on Wheat and a Smut attacks Corn. Almost everything which comes to the market is subject to one disease or another.

People who study the diseases of plants are called *plant pathologists*. They study the diseases and try to find ways of preventing them. They save the country millions of dollars every year by reducing the losses from plant diseases.

CHAPTER VIII

LABORATORY STUDIES

A six-inch celluloid ruler, with inches subdivided into sixteenths on one side, and the centimeters and millimeters of the metric system on the other edge, bears the advice, "study nature not books." Better advice would be, "study nature *and* books."

First-hand knowledge, which comes from a study of the plants themselves, is easily remembered; and, after such a study, one can understand much better what he reads about things in books. One could not learn much about chemistry or physics without the apparatus and experiments; but one needs the books also, if he is to learn much in the short time which can be devoted to the subjects. In botany it is just as necessary to study the plants themselves and just as desirable to have books, if we are to learn much in a limited time.

There should be frequent conferences or recitations covering both reading and laboratory work. For each laboratory period definite directions should be written on the blackboard, covering such material as has been secured.

Formal lectures are not necessary but the teacher can, in a minute or two, tell where the material came from and add any items of interest. If there are lantern slides, an occasional talk will be worth while.

Apparatus and Drawing.—For the laboratory work of Part I very little apparatus is needed. A sharp penknife, or a scalpel, or a safety razor blade will do all the necessary cutting; and a couple of needles, shoved into a couple of pine handles about the size of a lead pencil, will be useful. Any kind of pocket magnifier or tripod lens, magnifying 6 to 10 diameters, will be sufficient. If there is one microscope for an entire class, it can be used for demonstration in the few cases in which microscopic structure is referred to.

There should be a good grade of paper, cut about 5 by 7 inches, with holes punched at the top to fit some standard holder. Use a good pencil not too hard. You will make mistakes and so will need an eraser. The art erasers from the 5- and 10-cent stores are very good. Some teachers prefer ink. It is more definite and requires more skill. In advanced work, nearly all drawings are made with pen and ink.

Let this be your method in laboratory work:

1. Study the plant or part of the plant.
2. Read what you can from books.
3. Study the plant again, for, after reading, you may see something you overlooked before.
4. With the plant before you, make an accurate drawing. Make drawings of all features which are to be noted or studied.

Always print the name of the plant. Some description may be written on the drawing itself, or suggestive letters may be used, *e.g.*, *m*, for midrib; *v*, for vein; *s*, for stalk, etc. The description can then be written under the drawing. The descriptions of figures, as they are given in this book, are full enough. If any further notes are made, they should be so carefully written that they will serve as exercises in English composition as well as botanical descriptions.

Laboratory Material.—For laboratory work it is not necessary to use the particular forms mentioned in the text; whatever is available will do. In different parts of the country and at different times of the year different things can be obtained. Throughout the laboratory directions more forms are mentioned than can be studied in a limited time, but it is hoped that some may be available in one part of the country or another; and even where none can be found, they may suggest similar local material.

The grocery is the place to get fruits and vegetables. In season, an auto ride into the country may bring an abundance of material. During a teacher's first year in any school, the problem of securing material may be difficult; but a second year is easy to provide for. Flowers and young fruits which will not be in season when wanted in the laboratory can be collected and preserved. Pint, quart, or two-quart fruit cans, according to the anticipated number of students, are good containers. One part of commercial formalin (formaldehyde) to twenty parts of tap water will preserve all the material the can will hold. Before using such material in class, rinse it in water for a few minutes, because formalin is irritating to the eyes. Any material which has not been damaged may be put back into the can.

Leaves can be pressed. The coarse absorbent paper used in pressing herbarium specimens is best. Blotting paper is good but is more expensive. First, lay down two sheets of the absorbent paper; on this, lay a sheet of newspaper of the same size. It is better to take a piece of newspaper of twice the size and fold it. Lay on as many leaves as the space will allow and cover with the other half of the folded newspaper. Then add two sheets of absorbent paper, put on the newspaper, the leaves, a thickness of newspaper, two sheets of absorbent paper, and so on.

Place a board on the pile of papers and weight it down with two or three bricks; great pressure is neither necessary nor desirable. If the absorbent paper is changed three or four times the first day, twice the second, and once a day thereafter until the leaves are dry, they will retain their color. It is not necessary to change the newspaper. If the leaves are merely put into the press, without any change of absorbent paper, they will show the structure, but will have a dull, brownish color. Flowers also keep their color pretty well, if pressed as recommended; but flowers are studied better from preserved material than from pressed. If studied from dried material, they should be soaked in hot water for half an hour before using.

Seeds can be put into pasteboard boxes, where they can be kept indefinitely.

When local material cannot be obtained, various laboratory supply companies will furnish almost anything. The following are a few of the better companies in different parts of the country:

The Thomas Botanical Supply Co., Charleston, Ill.

General Biological Supply House 761–763 East 69th Place, Chicogo, Ill.

M. S. Markle, Earlham College, Richmond, Ind.

Marine Biological Laboratory, Woods Hole, Mass.

Triarch Botanical Products, Ripon, Wisconsin.

Albert Galigher, 1700 Marin Ave., Berkeley, California.

Directions for making microscope slides are given in the laboratory directions for Part II.

THE LEAF (Chapter I)

Get various leaves. Living leaves are the best, but well-pressed leaves are very good. The leaves mentioned in the text show considerable variety but others, just as good, will be found in various parts of the country.

Forms and Veins.—For a simple leaf with an entire margin try the Lilac, Milkweed, Cranberry, Blueberry, Huckleberry, India Rubber Plant, or look for others. Leaves with a toothed (serrate) margin are easier to find. Are most leaves heart shaped, rounded, or straight across at the base? Are they pointed, rounded, straight across or notched at the top?

Do the veins run independently, or do they unite more or less with each other? Draw the outline and put in the veins which can be seen easily with the naked eye. A good pocket lens will usually show even the smallest veins.

Study leaves like those of the Elm, Beech, Birch, Alder, Chestnut, Hazelnut, Apple, Peach, Basswood or any which may be available.

Get leaves of various kinds of Maples and Oaks, like Sugar Maple, Red Maple, Soft Maple, Norway Maple, and Red Oak, White Oak, Black Oak, Live Oak. Hunt any other leaves with outlines somewhat like those of the Maples and Oaks. Can you find anything in the veins which would cause the difference in the outline of the leaves of Sugar Maple, Red Maple, and Soft Maple; or the difference in the outline of leaves of the Red Oak and White Oak?

For compound leaves study the Rose, Blackberry, Raspberry, Strawberry, Locust, Pea, Ash, Hickory, Walnut, Sumac, *Ailanthus*, Horse Chestnut, Virginia Creeper, Boston Fern, Bracken Fern, or any others.

Among the leaves studied, which ones have stipules and which ones lack them?

If leaves of the Cottonwood Poplar or Aspen Poplar can be secured, look at the leaf stalks. They are like a thin band, while most leaf stalks are more or less round in cross-section.

Note the parallel veins in Corn, Grass, *Iris*, Cat Tail, Lily, Onion, Banana, Palm, Pine, Fir, Spruce, Juniper or any others. Do you find any toothed or lobed margins when the veins are parallel? Note the sheathing base of the leaf in Corn and Grass.

If possible, look at big leaves which you can not bring into the laboratory, like those of the Century Plant, Amazon Water Lily, and others.

Note the surfaces of the various leaves you study. Are they smooth, rough, dull, shiny, or velvety? Are they thick or thin? Do they wilt soon when removed from the plant, or do they remain fresh for some time?

Microscropic Structure.—Look for stomata. In many leaves you can see them with a pocket lens. They generally appear as very small whitish dots. If a microscope is available, the stomata are easily seen by looking down on the under surface of almost any leaf. By stripping the epidermis from the lower side of a Lily leaf, placing a drop of water on it, and adding a thin cover glass, very clear views of stomata are easily obtained.

Sections of leaves are not hard to cut. This is an easy way if you have several leaves: Cut 20 or 30 rectangular pieces about 1 inch long and ¼ inch wide; pile them up so as to form a mass 1 inch long and ¼ inch square. Hold the mass between the thumb and finger of the left hand and with a safety razor blade cut sections as thin as you can. Some of them will be thin enough for good microscopic work. Mount the best sections in a drop of water and cover with a thin cover glass.

Note the upper and lower epidermis. They are only one cell thick and are likely to be colorless, except at the stomata, which are likely to be green. Most leaves have elongated cells, closely packed, and perpendicular to the upper surface, while the cells of the lower half of the leaf are not elongated and are loosely arranged. In nearly all the cells there will be green bodies, the chloroplasts containing the green coloring matter called chlorophyll, which enables the plant to manufacture organic food from inorganic food substances. Most of the sections will contain veins. Their cells do not contain chlorophyll, but they conduct substances to the green cells, and conduct the manufactured food product back to places where it is needed.

Ecology.—If the Mermaid Weed is available, note the difference between the leaves under water and those above water. Other leaves may be just as good in your locality.

Note the character of the leaves of desert plants. Many such plants are grown in rock gardens. A fleshy leaf holds water for a long time.

The Sundew, Venus Fly Trap, Pitcher Plant and others will be found in one part of the country or another, and sometimes they can be found in greenhouses. Examine them and find why they are called insectivorous plants.

Study the rosette arrangement of leaves in Dandelion, Plantain, Evening Primrose, and any others. Examine the leaves of Ivy on buildings and note how the leaves are arranged so as not to shade each other. These arrangements of leaves are called *leaf mosaics.*

Note the day and night position of leaves. *Oxalis*, Clover, Peas, and Locust are good. The Sensitive Plant is best of all, because the night, or sleeping position, is assumed instantly when the plant is touched. How does the sleeping position benefit the plant?

If the Compass Plant is in your vicinity, look at it from the east and from the west, and note how different the view is from the north or south.

The Rosin Weed and Prickly Lettuce show the compass habit in some degree.

For reduced leaves, study the Cactus, Horsetail, Australian Pine, or anything available.

Physiology.—Try the experiment described on page 20 to show that the plant gives off oxygen in sunlight. With a large funnel and a large test tube enough oxygen can be collected for striking experiments.

The starch tests described on page 21 are not difficult. Put the black paper on gently and put it on both sides of the leaf. A plain strip of black paper, on opposite sides of the leaf, fastened gently so as to shut out the light both from above and below, is all that is needed; but it is more interesting if you cut your initials through the paper. A small sharp negative often gives a good print, especially if a piece of black paper be placed on the under side of the leaf opposite the negative. Similarly, if a strip of black paper, with a name cut through, be placed on an apple just before it begins to turn red, the name will be in red, against a light-colored strip of background.

To show that the leaf gives off water, take a leaf—a Geranium leaf is good—and put the leaf stalk through a hole in a piece of cardboard. Then place the cardboard over a tumbler nearly filled with water and cover with an empty inverted tumbler of the same size. Drops of water will soon appear on the upper tumbler. Bright sunlight hastens the process.

In plants out of doors and in the house, note how cleanly the leaf breaks off when it falls. The wound on the stem is nearly healed before the leaf breaks off.

THE STEM (Chapter II)

Classify plants in your vicinity into Herbs, Shrubs, and Trees. Classify them into annuals, biennials, and perennials.

The Coarser Structure of Stems.—Note the branching of trees. Which ones in your vicinity have a strong main trunk with side branches; and which ones break up into branches of more nearly equal size, so that it is not easy to follow a main axis? Make sketches of the two types of trees, and also of an herb and a shrub.

Make a drawing of any rhizome you can find. *Iris*, Solomon's Seal, May Apple, the Bracken Fern, or any others will do.

Sketch the corm of Jack-in-the-pulpit, Crocus, Cyclamen or any other.

Sketch a bulb of an Onion; then cut it lengthwise through the middle and sketch.

Study nodes and internodes. They are most striking in Corn, Bamboo, and other Grasses. The Horsetail, or Scouring Rush, is good. Nodes and internodes will be well marked in any plants with opposite leaves; but when leaves are scattered (*alternate*), the part of the stem between two leaves is a node, even if it is not so sharply marked.

Collect as many kinds of twigs as you can find. In summer and in autumn note the young buds in the axils of the green leaves and also the leaves and bud scales of previous years. In winter and early spring note the leaf scars, buds, and lenticels. Always make sketches.

Cut crosswise and lengthwise the largest buds you can find and sketch the arrangement of leaves. Are the buds hairy, smooth, sticky, or rough?

In winter bring twigs with buds into the laboratory and place them in a jar of water in good sunlight. How long does it take the buds to open? Do the bud scales fall off or dry up and stay on? How can you determine the age of a twig?

Can twigs of Oak, Hickory, Pecan, Ash, Poplar, Alder, Birch, Apple, Peach, *Ailanthus*, Sumac, Horse Chestnut and others be distinguished from each other after the leaves have fallen?

In any of the twigs in your vicinity can you distinguish the leaf buds from the flower buds?

Study a twig of Pine, Fir, Spruce, Juniper, or any cone-bearing tree. Where are the buds?

Cut across the stem of the common garden Sunflower. Make a sketch showing pith, wood, cortex, and pith rays. Are there any growth rings?

Make a similar study of the stem of Corn or any other plant with parallel-veined leaves.

Cut a cross-section of a twig of Basswood or any other tree. How do the proportions of pith, wood, and cortex compare with those of the Sunflower? Count the rings. Make a drawing showing the pith, wood with growth rings, pith rays, and cortex. The epidermis might be shown in the stem sections, but it is so thin that it would be only a thin line.

Look at the rings on a stump or log. Are the widest rings near the center or near the outside? The lighter colored wood at the outside is the sap wood and the rest is heart wood. About how many rings are there in the sap wood?

In a horizontal branch, is the pith in the center or a little to one side?

In any board, but especially in Oak, Ash, Hickory, and others with a prominent grain, can you follow the growth rings? Can you recognize the pith rays?

Look at the trees in your vicinity. Can you distinguish them by their bark? Compare the bark of the Elm, Basswood, Maple, Ash, Hickory, Pecan, Sycamore, *Eucalyptus*, Birch, Madrona, Pine, Juniper, and others.

Microscopic Structure.—If a microscope is available, note the structure of some stem, preferably a woody stem, which will show growth rings. A thin section can be cut with a safety razor blade. Put it on a glass microscope slide, add a drop of water and a cover glass, and examine. Note the thick walls of the cells of the summer wood and the thinner walls of the cells of the spring wood. The larger vessels are in the spring wood.

Take a piece of stem of young Sunflower, or any other, cut out a piece and see whether you can cut into it and pull it apart so as to show the spirals as indicated in Fig. 45.

Physiology.—Take about a foot of the top of some soft stem like *Coleus*, *Geranium*, or Touch-me-not, hold the lower end under water and cut off a thin section at the bottom so as to have a freshly cut end in the water. Add a little eosin to the water. In 10 or 20 minutes examine the stem by making cross- and longitudinal sections. How far has the colored liquid

gone up into the stem? Has it soaked through the whole stem or has it gone up only in certain parts?

This experiment proves that the liquid rises in the stem. In what part of the stem does the liquid rise? Remove, carefully, from a woody twig as large around as a lead pencil or larger, a band of bark about a quarter of an inch wide. Does the water rise or do the leaves soon wilt? Is the downward movement of liquids in the wood or in the bark? After a week see whether there is any swelling or formation of roots in the bark at the upper part of the cut.

Try the experiment with the potato described on page 53.

Plant seeds of the Bean and try the experiments on heliotropism and geotropism described on page 55. Make sketches to show your results. Try the same with Corn, and, when the root and stem are about one inch long, turn the plant upside down and see whether the root and stem can adjust themselves to the changed conditions.

Diseases.—If there are Mushrooms, Toadstools, or Bracket Fungi on any trees or at the base of trees in your neighborhood, note whether the trees look healthy. If any trees have been blown down or large branches have been blown off, note whether there are rotten places. Many diseases of trees are caused by Mushrooms, Toadstools, Bracket Fungi, and other plants of this sort.

THE ROOT (Chapter III)

Plant seeds of Bean, Mustard, Flax, Corn, Grass, and Wheat, planting some in soil and simply laying some on wet filter paper. Try some of the Corn as indicated on page 60.

Note the two types of roots—tap roots and fibrous roots. Where do you find root hairs? Note primary roots and secondary roots.

Look for seedlings out of doors. Oak, Maple, Basswood, with any other woody plants and various weeds will be worth while. Which type is commonest, the tap root or the fibrous root?

Look for fleshy roots. You may find some out of doors and can find Turnips, Carrots, Radishes, Sweet Potatoes, and perhaps others at the grocery. Sketch various forms.

Study adventitious roots of Corn, Solomon's Seal, or any others. In greenhouses of city parks, look at the adventitious roots of the Screw Pine, Orchids, *Monstera*, and others. Note the big root caps on the adventitious roots of the Screw Pine.

If you have a branching India Rubber Plant, get a new plant from one of the branches, as described on page 67.

Cut cross-sections of roots of the Bean and Corn. How do they differ when examined with a pocket lens? If there is a microscope, make very thin sections and note how the structure differs from that of a stem.

THE FLOWER (Chapter IV)

Get some rather large simple flower for the first study. *Trillium, Geranium*, Mustard, Stonecrop, or similar flowers are good.

Structure of the Flower.—Sketch the flower, showing flower stalk, sepals, petals, stamens, and pistil (or pistils). Also make a floral diagram.

Sketch a Lily or Tulip or some similar flower in which the sepals and petals are alike. Always make a floral diagram. Sketch a diagrammatic longitudinal section showing the perianth, stamens, and pistil all growing on top of the receptacle.

Sketch a stamen of a Lily or Tulip, showing filament and anther. Cut the anther in two crosswise and note the four microsporangia.

Sketch the pistil, showing ovary, style, and stigma. Cut the ovary in two crosswise and make a sketch showing the ovules. The internal structure cannot be seen without a good microscope and thin well-stained sections. Make a floral diagram.

Study any other flower with separate petals, like the Apple, Peach, Cherry, Bean, Violet, Crowfoot, Anemone, or whatever may be available.

Study some flower with a sympetalous corolla, like Morning Glory, Sweet Potato, Potato, Snap Dragon, Foxglove, Blue Bell, or any others. Make a habit sketch and always the floral diagram.

Study the dioecious flowers of some plant like the Willow, Poplar, or Wild Hemp; and the monoecious flowers of Corn, Birch, or any other plant with stamens and pistils on the same plant but in different flowers.

Sketch an example of each kind of indeterminate flower cluster—raceme, corymb, umbel, spike, head, spadix, catkin, and panicle. Some examples are given in the text, but you may find others just as good.

Sketch two or three determinate flower clusters. All of them may be called cymes. *Hydranga*, *Phlox*, and Elder are good examples, but this type is not so common as the indeterminate.

Look for peculiar flowers like the Indian Pipe, Goose Plant, Columbine, Orchids, *Canna*, Bird of Paradise, etc.

Microscopic Structure.—If there is a microscope, look at sections of the anther showing pollen grains, each with its generative nucleus and tube nucleus.

Look at section of the pistil showing ovules with megasporangia and integuments, and, inside the megasporangium, the megaspores. At a later stage you may see, inside the megasporangium, the embryo sac, with its egg, two synergids, endosperm nucleus, and three antipodal cells. This microscopic work is difficult, and it will not be worth while to make sketches unless each student has the use of a microscope for at least two hours.

Pollination.—Pollination is a very important subject, but it is one which cannot be studied in the laboratory. Study it in the field, if possible. Read the text thoroughly.

If there is a good preparation and a good microscope, the egg, containing its own nucleus and also the sperm nucleus which came in from the pollen tube, can be seen quite clearly. The sperm nucleus looks denser and stains more deeply than the nucleus of the egg. Make a sketch of an egg containing the two nuclei. The union of these two nuclei constitutes fertilization.

Who was Mendel? What are hybrids? What practical value is there in crossing plants?

Throughout the work, study with even greater care the descriptions and illustrations of those things which you cannot find in the laboratory or the field.

THE FRUIT (Chapter V)

The garden, the orchard, and the grocery, with lawns and vacant lots, will furnish material for a study of fruits. It would be well to keep on hand preserved material of flowers and early stages in the development of such fruits as are not likely to be obtained when they are wanted.

Review what was said about carpels and the receptacle, because these structures form such an important part of so many fruits. Most ovaries are made up of carpels. The receptacle is the end of the flower stalk bearing the calyx, corolla, stamens, and carpels.

Fleshy Fruits.—Get as many fleshy fruits as possible and try to classify them.

The Berry.—The Grape and Tomato are typical berries. Other suggesions are Gooseberry, Currant, Cranberry, Blueberry, Huckleberry, Ground Cherry, and Persimmon. Wherever floral parts are carried up on top of the fruit, as in the Gooseberry, a part of the fruit consists of receptacle, which grows up along with the carpels.

In citrous fruits, like the Orange, Lemon, Tangerine, and Grapefruit, study the mature fruit. Note the general structure in longitudinal and cross-sections; note juice sacs and the glands in the skin.

Seeds of citrous fruits germinate readily and often more than one seedling develops from a single seed.

In the Banana, note the skin, which is mainly receptacle, and note the small, abortive seeds.

The Drupe.—The Peach is a typical drupe. Note the habit and sketch it in longitudinal sections. There are many bundles in the fleshy part. Are there any in the stone? Are there any bundles in the seed? Can you see where the seed is attached? The Apricot, Plum, and Almond are similar. The Cherry shows about the same structure on a smaller scale. If flowers are available, note the relation of the flower to the fruit.

The Aggregate Fruit.—The Blackberry, Raspberry, and Loganberry are typical aggregate fruits. Sketch any of them. Can you identify calyx, stamens, and style? Does the individual drupelet differ much from a Peach?

The Pome.—The Apple is typical. Study it in surface view and in both longitudinal and cross-sections. Find the limits of the pith and cortex of the receptacle. Try this first in cross-section and then in the longitudinal section. Sketch the cartilaginous and the fleshy part of the carpels. Where are the seeds attached? Can you identify calyx, corolla, stamens, and the tops of the carpels at the top of the Apple? The Pear and Quince are quite similar; but in the Crab Apple and Thorn Apple the carpels are very hard.

The Pepo.—The Cantaloupe is a good type for study. The seeds are attached to the carpels. In cross-section you will see three carpels attached

to the ovary wall. Most of the edible part consists of receptacle. Can you find any trace of calyx, corolla, or stamens?

Compare the Cucumber. Here we eat both carpels and receptacle. Can you find the limits of the carpels and receptacle?

Compare also the Watermelon, Squash, and Pumpkin. A comparison of the flower with the ripe fruit will help you to find the limits of carpels and receptacles, and you may not be able to find these limits without looking at flowers.

The Multiple Fruit.—Study the Mulberry. It looks like a Blackberry, but it comes from a flower cluster, while the Blackberry comes from a single flower. This is easily seen, if you have both flowers and fruits. Can you see the difference between the two without the flower to guide you? Study the Pineapple, both in surface view and in longitudinal and transverse sections. If you have room, plant the leafy top and see whether you can make it grow.

The Accessory Fruit.—The Strawberry is our most familiar example. Sketch the ripe Strawberry, showing calyx, stamens, pistils, and receptacle. Compare with the flower just before the petals fall.

Cut a longitudinal section of a half grown Fig. The Fig consists of a cup-shaped branch, with the inside of the cup lined with flowers. Compare with the ripe Fig.

Study any ovulate Pine cone. Where are the seeds borne?

Sketch an Artichoke in surface view and in longitudinal section. Note the bracts and the flowers. Compare with the head of any Thistle.

Dry Fruits, Dehiscent.—Whenever material permits, note how the fruit splits (dehisces). It is interesting to see where and how the splitting takes place.

The Legume.—Peas and Beans are our most familiar dehiscent fruits. Sketch in surface view. The pod consists of one carpel, like a leaf with a midrib. The blade of the leaf, bearing the ovules (Peas, Beans), is folded in so as to form a closed ovary cavity. What parts of the flower are still visible in the ripe fruit?

The Capsule.—Lily and *Iris* are good examples. Note how the seeds are arranged. Do the seeds of the Lily and *Iris* look alike? Compare the capsules of Shepherd's Purse, Violet, and Horse Chestnut.

The Pyxis.—The Plantain is our best example. Study it when the spike has reached its full length but has fruits still reddish or purplish, and then compare with fruits whose lids are falling off.

Dry Fruits, Indehiscent.—The indehiscent fruit has no regular method of splitting; it simply decays or is fractured by the germination of the seed.

The Akene.—The Buckwheat and Buttercup have akenes. The fruit of the whole composite family is also put here. You can dissect the seed out from the ovary without any difficulty, because the seed and the ovary wall do not grow together.

The Grain.—The Corn is best for study. A grain of Corn is like the Buckwheat, except that the ovary wall sticks to the seed so closely that

you cannot separate them. The same is true of Wheat, Oats, and other cereals.

The Nut.—The Hickory Nut, Pecan, Walnut, Butternut, Hazel Nut, Chestnut, Acorn, Brazil Nut, and Cocoanut are familiar examples. Try any of them and identify the embryo, seed, and ovary.

The Key.—The Maple, Box Elder, Ash, Elm, and Hop Tree are good examples. Note the seed and what part becomes the wing. If you have opportunity to see these seeds fall, note how far they may be carried from the tree.

THE SEED (Chapter VI)

What is a seed? Study the origin and structure of the seed in Figs. 119, 120, and see what features you can recognize in the seeds which are brought into the laboratory.

Structure.—Study various seeds, especially larger ones, like Buckeye, Bean and Date. Smaller ones, like the Morning Glory, Buckwheat, *Iris* and Lily are good. Note the seed coats, embryo, and endosperm.

Sketch several seeds to indicate the method of seed dispersal. Sand Bur, Cockle Bur, Burdock, Spanish Needle, Tick Trefoil, and Devil's Cork Screw may be suggested, but if you tramp through the woods or weedy fields, you will bring in many which you may not have seen before.

Dispersal.—For seeds or fruits which are scattered by wind, study Maple, Ash, Pine, Catalpa, Box Elder, Basswood, Thistle, Dandelion, Willow, Poplar, Milkweed, Cotton, and any others.

Germination.—Germinate various seeds. Germination will usually be hastened if you soak the seeds in water for 24 hours. Try Beans, Corn, Wheat, Oats, Grass, Onion, Lily, *Iris*, Date, Water Plantain, Arrow Leaf, Apple, Peach, Orange, Lemon, Grapefruit, Morning Glory, Pumpkin, Cucumber, Pine, and any others which may be available. It is not necessary that all should study the same seeds, except that everyone should study Beans and Corn.

In the Bean the endosperm is soon used up by the cotyledons, so that you do not see any endosperm in the ripe seed. After the soaking in water, dissect off the seed coat. The embryo consists of two large fleshy cotyledons, a root and a stem (plumule). Sketch the various parts.

Sketch a Bean seedling three or four inches long and label the various parts. The part between the cotyledons and the root is called the hypocotyl; and the part above the cotyledons is the epicotyl. These two Greek words mean *below* the cotyledons and *above* the cotyledons.

Sketch any seedlings in which the cotyledons look very different from the foliage leaves, as in Basswood, Maple, and many weeds.

Soak Corn and dissect off the ovary wall, which looks like a seed coat. Dissect out the embryo. The largest part of it, lying against the endosperm, is the cotyledon. There is supposed to be only one cotyledon in Corn and other Monocotyls.

Sketch any other seedlings. Which ones have two cotyledons and which seem to have only one?

How does the seedling of a Bean differ from that of a Pea? If you can find an Oak seedling or germinate an acorn, note that the cotyledons stay in the seed. Where is the stem tip in an Onion seedling two inches long?

Germinate Pine seeds. The seeds of Pinon, the edible pine, are large and germinate easily, if they have not been roasted. This seedling has several cotyledons, and the seed coat is carried up on top of them.

With seedlings growing in the laboratory, review the observations on roots and repeat the experiments on Heliotropism and Geotropism.

VARIOUS IMPORTANT TOPICS (Chapter VII)

Vegetative Propagation.—Some of the methods of vegetative propagation may not be easy to repeat in a city school, but in the country, or where there is access to the country, most of the methods mentioned can be tried. In a city school, operations like budding and grafting can be made on twigs and branches, even if they are not to grow.

The Rhizome.—Cut the rhizome of Couch Grass or Canada Thistle into pieces two or three inches long and cover them with soil. Keep them moist but not too wet. How long before new buds begin to appear?

The Stolon.—Raspberry, Gooseberry, and Grape are good for this type of reproduction. Bend over a vigorous young shoot and cover the tip with soil. How long before roots appear? White Clover will strike root more quickly.

The Runner.—Try the Strawberry. If you cover a part of the runner with soil, buds will appear sooner.

The Sucker.—Corn is good for this type. Suckers may appear quite early in plants grown in pots in the schoolroom.

Cuttings.—This is the easiest method to try in the schoolroom. Cut *Begonia* leaves into triangular pieces with the margin of the leaf forming one of the three sides. The sides of the triangle should measure about an inch and a half. Stick the piece edgewise into moist sandy soil, with the margin part at the top. Keep them moist but not too wet. How long before the piece begins to show roots?

Bryophyllum leaves will produce new plants if you simply lay the leaves down on moist soil. If the air is moist, new plants will grow out from leaves hung up by a string.

If you have an India Rubber Plant which is getting too tall, cut the stem as described in your text and tie a handful of Peat Moss around it. Keep the moss wet. When the roots are about an inch long, cut the stem off just below the moss and pot it, without removing the moss. If your plant is branching, try the same method with the side branches.

If you pot the top of a Pineapple, it soon strikes root and will develop into a plant looking somewhat like a Screw Pine.

Budding.—Practice making T-shaped cuts, spreading the bark a little near the top of the T. Cut out buds and slip them into the T-shaped crack. Then tie the cut together. If you expect the bud to grow, the knife must be clean and sharp. If you are in an Orange part of the country, you will have ample opportunity to watch budding as it is done in the most skillful way.

Grafting.—If you are in an Apple section of the country, you will see various types of grafting done in the most approved manner.

Practice on a twig about three-fourths of an inch in diameter, with a cion about one-eighth of an inch in diameter. Make the cut in the top of the stock quickly; taper the base of the cion to a wedge shape, with a good bud at the top of the wedge. Push the cion into the crack at the top of the stock and cover quickly with wax. If the operation is too slow, the surfaces dry and the cion is not likely to grow.

Classification.—With the knowledge gained up to this point, the student should be able to identify the easier flowering plants with a manual. If a manual is available, try some familiar plant like a Lily, a Morning Glory, or a Potato.

Compare the leaves of any Maples you can find and read what you can about species. Try the leaves of Oaks in the same way.

Morphology.—Most of the laboratory directions have dealt with morphology. This phase of botany is particularly important, since not much can be done in any other line of botany without a knowledge of plant structures.

Ecology.—If field trips can be arranged, the elements of ecology can be pointed out. Professor Cowles's treatment of this subject in the textbook by Coulter, Barnes, and Cowles is to be recommended.

Physiology.—There is no satisfactory elementary textbook of plant physiology. The textbook of botany by Transeau emphasizes the physiological side of botany. "The Living Plant," by Ganong, is also good.

Forestry.—Here, too, there is no good elementary textbook. In some parts of the country much can be learned by visiting forests and lumber camps.

Plant Breeding.—Experiments here take time; but where there is opportunity, it would be worth while to cross different varieties of Corn. Cross garden Peas having smooth seeds with those having wrinkled seeds; or cross tall plants with short. Mendel's work with garden Peas can be repeated if you have a garden.

Plant Diseases.—Plenty of material for an observation of many types of disease can be picked up almost anywhere. Notice the condition of trees which have Bracket Fungi on them, or have Mushrooms or Toadstools at the base.

Watch Grapes for a few days. If you break the skin of a Grape, how long is it before a greenish mold appears?

If a slice of bread is exposed to the air, how long is it before a white mold appears? After the white mold, a blue mold is likely to appear; and, after that, a very black mold or a bright orange one.

In the various fruits and vegetables from the grocery, do you find any which do not, sooner or later, develop some disease or other if exposed to the air?

If you have opportunity, look at Corn Smut, Wheat Rust, Peach Leaf Curl, Club Root of Cabbage, and other diseases. What effect do they have upon the plant?

PART II

DEVELOPMENT OF PLANTS FROM THE LOWEST TO THE HIGHEST

STRUCTURE AND DEVELOPMENT OF PLANTS

In Part I we studied, almost exclusively, those parts of the higher plants which can be seen without a microscope. In Part II we are to study a series of plants from the lowest and simplest up to the highest and most complex. Some of the higher plants which were studied in Part I will be studied again from a different standpoint.

There have been so many classifications, especially of the lower plants, that it would be out of place to discuss them here. We shall simply arrange the material under Thallophytes (Algae and Fungi); Bryophytes (Liverworts and Mosses); Pteridophytes (Lycopods, Equisetums, and Ferns); and Spermatophytes (Gymnosperms and Angiosperms).

Life histories and the progress from lower to higher forms will be the principal features of Part II.

The directions for laboratory work include suggestions for collecting, preserving, and studying material, and present some practical methods for making permanent microscope slides.

CHAPTER IX

THALLOPHYTES

The lowest of all plants belong here. Many of them are so small that they cannot be seen with the naked eye, while others may reach a hundred feet in length. Usually there is nothing which even looks like a root, stem, and leaf; but a few Thallophytes have a stem with leaves. None have roots. The archegonium, which characterizes plants above the Thallophytes, is entirely lacking. In general, the structure is simpler than in the groups which follow. On the whole, the characterization of the group is not very definite, although botanists think they know what forms should be included here and what ones should be assigned to groups higher up.

It is customary to divide the Thallophytes into two groups, the Algae and the Fungi. Algae are characterized by the green coloring matter called chlorophyll, while the Fungi have no chlorophyll and are usually colorless.

ALGAE

Most of the Algae grow in water. They are the lowest forms of plant life. Their green coloring matter, chlorophyll, enables them to make usable food from inorganic substances. Animals cannot do this and, consequently, are dependent, directly or indirectly, upon green plants. It follows, naturally, that plants originated before animals and that Algae are the lowest of living things.

There are four groups of Algae, all having the green coloring matter called chlorophyll. One of them has no other coloring matter and its various members have a grass green color; but the other three have an additional pigment which obscures the green and produces a blue green, brown, or red color. The four groups are called the Cyanophyceae (Blue Green Algae); Chlorophyceae (Green Algae); Phaeophyceae (Brown Algae), and the Rhodophyceae (Red Algae).

Blue Green Algae (Cyanophyceae).—The Blue Green Algae have a bluish pigment, *phycocyan*, in addition to the chlorophyll, and different proportions of these two pigments give the members of this group a light blue green color, or a deep blue green, or a medium blue green; so that Blue Green Algae is a good name. Some forms are brownish and a few are nearly black.

The cell structure is very simple. We have used the word, cell, before. We have not defined it or described it and we shall not describe it now, but shall merely state that the cell is the unit of structure of which all living things are built. A plant consisting of one cell is *unicellular;* if it consists of more than one cell, it is *multicellular*. If a multicellular plant has its cells arranged in a single row, it is *filamentous*. The cells may be in thin plates one cell thick, or they may form a solid, several cells thick. But whether the plant consists of one cell, or of a filament, a plate, or a small solid, or a big solid, like a tree, the unit of structure is the cell.

A cell usually has a cell wall and the cell contents consist, principally, of *protoplasm*, containing a rounded body called the *nucleus*. The cell, with its various contents, will be studied in detail when we take up the microscopic structure of the flowering plants.

The cell structure of the Blue Green Algae is very simple. The nucleus is not marked off sharply from the protoplasm and the very small droplets of coloring matter are scattered loosely throughout the protoplasm, not being held in special color-bearing structures as they are in plants above this group. There is a definite cell wall, and it usually secretes a mucilaginous substance, forming a sheath around the cell or filament, so that these algae are nearly always slippery.

A study of some typical members of the Blue Green Algae will give more definite ideas than can be secured by reading, without seeing the things themselves.

Gloeothece.—Gloeothece is a unicellular form, very common in greenhouses, where it floats on water in tanks containing such water plants as are generally used in aquaria. Sometimes it is found on flower pots which are kept rather moist; and it forms a gelatinous coating on rocks or on stone walls of damp cellars.

The series in Fig. 141 shows how *Gloeothece* develops. The single cell divides, so that there are two cells within a single sheath; each new cell forms its own sheath and then divides. Each of these new cells forms its own sheath and the process continues; but when a stage like that shown in *D* has been reached, the outer sheath has become so weak and watery that it begins to break down, thus freeing the groups of cells inside. Occasionally, a cell may form several sheaths without dividing, as shown at *A*, and often more than one sheath will be formed before a cell divides again.

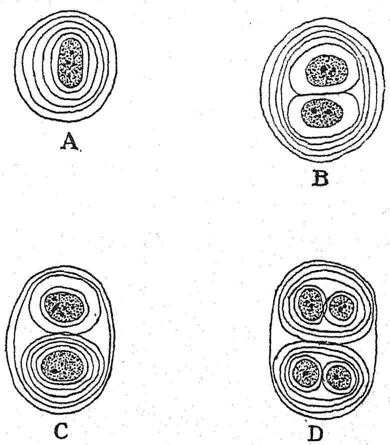


Fig. 141.—*Gloeothece.* A one-celled Blue Green Alga. *A*, single cell (shaded with several sheaths; *B*, two-cell stage; *C*, two-cell stage in which one cell has made more sheaths than the other; *D*, four-cell stage. × 550.

Gloeocapsa looks much like *Gloeothece* and the two forms are often mistaken for each other; but the cell in *Gloeothece* is elongated while that of *Gloeocapsa* is spherical. The two are found in the same kind of places.

Oscillatoria.—This is the best known filamentous member of the Blue Green Algae. It is very common on damp pots in greenhouses; it floats in patches, from the size of a dime to the size of one's hand, on the surface of ponds and ditches; and it is abundant at the outlet of a sewer. Many Blue Green Algae seem to prefer dirty water.

Oscillatoria gets its name from its movements, swaying (oscillating) back and forth. It also has creeping movements. If tufts the size of one's finger nail be placed in a few drops of water on a sheet of white paper, many of the filaments will creep out from the general mass before the drops dry up.

Mount a small quantity of living material—a piece as thin as a sheet of writing paper and about one-eighth of an inch square—in a drop of water and add a thin cover glass. The swaying (oscillating) movements will be conspicuous, especially if the room is warm. Look for the features shown in Fig. 142.

Much can be seen in material in the living condition and such material should always be studied when possible; but many things can be seen in stained material which cannot be seen at all or can be seen only dimly without staining. The concave cells stain deeply and the nucleus, consisting of granules which stain sharply, is not marked off very definitely from the proto-

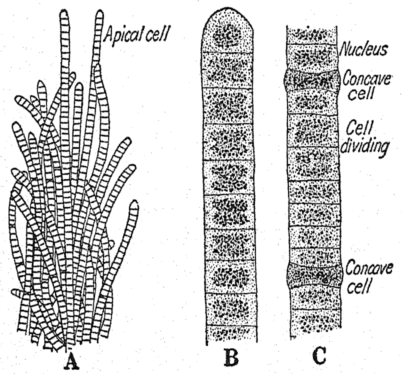


FIG. 142.—Oscillatoria. *A*, habit sketch of a group of filaments, × 125; *B* and *C*, filaments showing apical cell, nuclei, dividing cells, and concave cells, × 900.

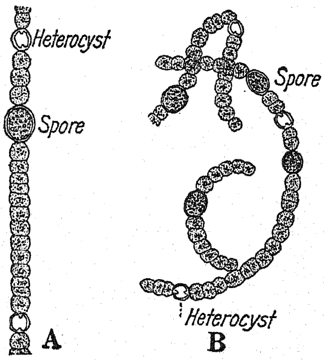


FIG. 143.—*Anabaena*. *A*, a species with straight filaments; *B*, a species with curved filaments. × 280.

plasm. On the other hand, some granules are dissolved and disappear when a preservative is used.

Oscillatoria occurs only as simple filaments without any branching. The concave cells break the filament into pieces called *hormogonia*.

Anabaena.—*Anabaena* is another filamentous alga without any branching, but it has several kinds of cells. There are vegetative cells which divide, as in *Oscillatoria;* but there are also cells so different that they are called *heterocysts* (different cells). Besides, there are cells which become larger than their neighbors, with denser contents and thicker walls. They may rest for a long time and then grow into filaments (Fig. 143).

Anabaena often floats on the water of quiet ponds, little lakes or lagoons, forming a scum which has the rainbow colors of a scum of oil; and the colors are due, partly, to very small droplets

of oil in the cells. The oil, being lighter than water, brings the filaments to the surface. The greenish color of the water in lagoons is often due to immense quantities of *Anabaena* and other Blue Green Algae.

Nostoc.—*Nostoc* is almost as widely known as *Oscillatoria.* It is found in the form of gelatinous balls from the size of a pinhead to masses as large as a golf ball. Each ball is made up of a large number of filaments whose sheaths stick together, thus forming the ball. Sometimes *Nostoc* takes the form of irregular sheets. The individual filament looks much like that of *Anabaena.* Heterocysts are numerous, but spores are rare (Fig. 144).

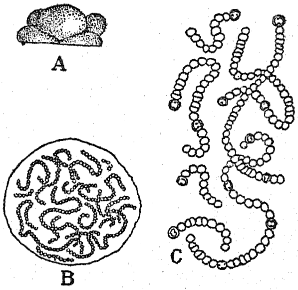


FIG. 144.—*Nostoc.* *A*, a group of Nostoc balls, natural size; *B*, a very young Nostoc ball, × 156; *C*, a few filaments. × 380.

These gelatinous balls take in water readily but do not give it up; consequently, they remain moist for a long time, even in dry weather. It is not unusual to find them, still moist, on dry ground where puddles have dried up weeks before. Some of the larger species are used for food in South America; one of them is called *Nostoc edule,* the edible *Nostoc.*

It is very easy to keep *Nostoc* alive in the laboratory. Put some balls in a quart can of water and add a little water occasionally to replace what is lost by evaporation. The culture should live and grow for years.

Gloeotrichia.—Some of the Blue Green Algae produce spores very abundantly. *Gloeotrichia* is one of these. It is found floating on ponds and ditches, in the form of soft, gelatinous balls, looking like the smaller balls of *Nostoc,* but lighter colored and so soft that it may break up as you collect it. In earlier stages, it is attached to sticks or stems, especially to dead branching flower stalks of grasses (Fig. 145*A*). The mass is made up of a large number of filaments, radiating from the center. The individual filament has a heterocyst at the base, followed by a long spore, and then a row of cells getting smaller and smaller, until the filament ends in a slender hair (Fig. 145*B*). The principal part of the sheath, which keeps the filaments

together in the form of a ball, is only at the base of the filament, so that the greater part of the filament projects beyond the sheath.

FIG. 145.—*Gloeotrichia.* *A*, balls of *Gloeotrichia* growing on Grass in water, natural size; *B*, a few filaments showing the heterocyst, long spore, sheath, and slender part of the filament tapering to a point. × 300.

General Remarks on Blue Green Algae.—Various members of this group grow as far north and south as plants can survive the cold. They are found beyond the Arctic Circle and beyond the Antarctic, where they may be frozen for years and then start to grow again when a summer warm enough comes around. They grow in the tropics, and many of them are at their best in hot springs, where the water is near the boiling point; and they are everywhere in temperate regions.

Some forms take up lime or silica in their gelatinous sheaths, so that they become stony Many of the beautifully colored terraces of hot-spring districts, like our Yellowstone Park, are built up of stony masses of these dead algae. In Italy stone formed in this way is one of the principal building materials.

Blue Green Algae pollute water and, as far as possible, should be removed from reservoirs which supply drinking water. Some

of them grow in salt water, but not where the water is too salty. They grow in the ocean, but not in Great Salt Lake or in the Dead Sea.

Green Algae (Chlorophyceae).—*Chlor-* means green and *-phyc-* means algae; so the common name is merely a translation of the scientific name. These algae have the green pigment, chlorophyll, and usually no other coloring matter. Consequently, their color is some shade of green.

Many of them are unicellular, but most of them are filamentous; some form thin sheets of cells and some of the salt-water members have very peculiar shapes.

They grow in all kinds of places, in ditches, ponds, rivers, lakes, and in the ocean. Some grow on damp rocks and on the ground; and a few grow in drier places on trees, especially near the ground. A few grow inside other plants, and Lichens are always made up of a fungus and an alga growing together.

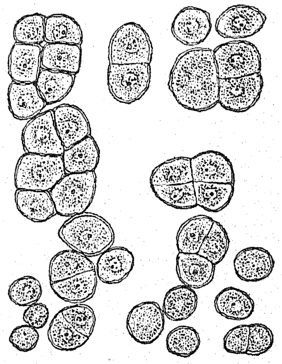


FIG. 146.—*Pleurococcus.* A one-celled alga growing on the bark of trees. The cells often hang together for a while, forming groups of six or eight or more cells. Drawn from living material. The green chromatophore occupies most of the cell. The nucleus in living material is rather indistinct. × 720.

Pleurococcus.—*Pleurococcus* is usually easy to find. Look on the bark of trees near the ground. It is more abundant on the north side of the tree and so serves as a compass, when one is in a strange locality, and the sun is covered by clouds. It is often found on fence posts and on boards, where it looks like green paint.

It is a unicellular alga, but, as it keeps dividing, the cells hang together in groups of two or three or four, and then they begin to fall apart. The cell wall is easily seen. The nucleus is almost colorless, but the rest of the cell is green. If a drop of weak iodine solution be allowed to run the under cover glass, some parts take a bluish color, showing the presence of starch. The cells keep dividing and falling apart, but there is no other mode of reproduction (Fig. 146).

Chlamydomonas.—This is also a unicellular member of the Green Algae. It is often found in aquaria, in jars in greenhouses,

and in puddles, ponds, and ditches. Cultures may be kept for a long time in the laboratory. A clean glass dish, holding about half a pint, or a butter dish from the 5- and 10-cent store, or a Petri dish will make a good container. Fill the dish about half full of clean white sand, with enough water nearly to cover the sand; then add a glass lid to prevent evaporation and to keep out various things which might get in from the air and spoil the culture.

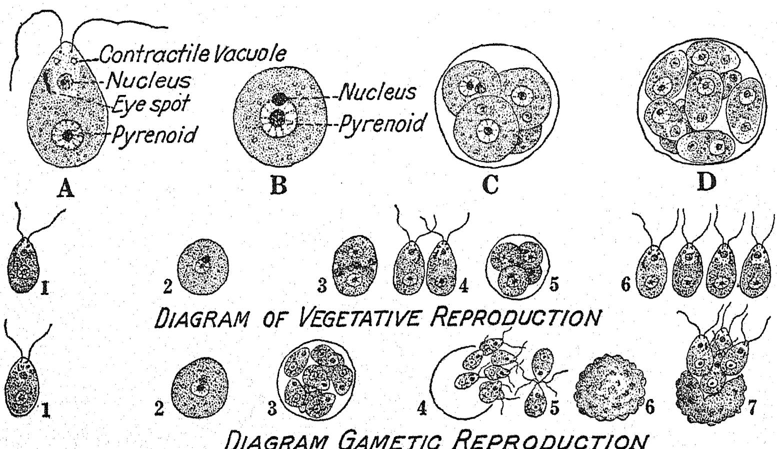


FIG. 147.—*Chlamydomonas.* *A*, vegetative cell the zoospore; *B*, the zoospore loses its cilia and rounds off; *C*, four new zoospores are formed within the parent zoospore; *D*, when eight new individuals are formed inside the parent zoospore, the eight are gametes. × 1,000. The second and third rows are diagrams of vegetative and gametic reproduction. Vegetative reproduction: 1, zoospore; 2, zoospore has lost its cilia and rounded off; 3, the rounded cell is dividing; 4, the rounded cell has divided, producing two zoospores; 5, the rounded cell instead of dividing as in 3 and 4, has produced four zoospores within itself; 6, the four zoospores have escaped from the rounded cell. Gametic reproduction; 1, zoospores; 2, the zoospore has lost its cilia and rounded off; 3, eight gametes are formed inside rounded cell; 4, gametes escaping; 5, two gametes uniting; 6, zygote formed by the two uniting gametes; 7, four zoospores escaping from the germinating zygote.

Chlamydomonas is of special interest because many botanists believe that from something like this the rest of the Algae could have been derived. If living material is available, mount some in a small drop of water and add a cover glass. Some of the cells may be swimming, and some may be at rest (Fig. 147).

The cell wall and the big green chloroplast with its pyrenoid are not very hard to recognize. The colorless protoplasm at

the front end can also be seen without much difficulty; but the colorless nucleus is not visible in living material and the cilia are not likely to be seen, except in sluggish specimens which are slowing down. The green chloroplast is entirely surrounded by protoplasm, but the layer is so thin, except at the front end, that it may not be noticed.

A drop of iodine solution will show that there is starch at the pyrenoid, and it may give enough of a faint brownish tint to the nucleus and cilia to make them visible. In stained preparations the nucleus and cilia should not be hard to find.

This life history should receive special attention, because it illustrates the fundamentals of life history not only in *Chalmydomonas* but in other algae and in higher plants.

After swimming about for a time, the zoospore loses its cilia, rounds off, generally increases in size, and may rest for some time. When the resting period is over, there are two ways in which the cell may behave—it may produce zoospores or gametes.

Zoospores are produced, four or eight in a cell, and each one is capable of living independently: it becomes an adult individual like the one which formed the resting cell; and, after a while, it loses its cilia, rounds off, becomes a resting cell, and the process is repeated over and over.

Or, the resting cell may produce a larger number of motile cells, usually 16. They look like the zoospores, except that they are much smaller; but, unlike zoospores, they cannot live alone. They come together in pairs, so that two individuals unite to form a single cell. When two cells unite in this way, they are called *gametes,* and the single cell resulting from the union is called a *zygote.*

The zygote increases in size and then becomes surrounded by a thick rough wall. In this condition it can withstand the cold of winter and does not suffer if the pond dries up. It may live for years and then start to grow when surroundings become favorable. The contents of the zygote swell, break the thick coat, and come out as four zoospores, which are really four individuals like the one with which we started.

Reproduction by a fusion of gametes is usually called sexual reproduction. *Gametic reproduction* is a better name and, from a scientific standpoint, is more exact. Reproduction by zoospores,

or by any other way than by a union of gametes, is called *vegetative reproduction.*

This may seem a rather long and hard description, but it is worth while to study it with the aid of Fig. 147; for thousands of other algae and higher forms of plant life have similar life histories. Many have only vegetative reproduction and many have only gametic; but more have both forms. If this life history of *Chlamydomonas* is studied thoroughly, there should not be much difficulty in understanding other life histories as you come to them.

Volvox.—*Volvox* is one of the show pieces of botany, if you can get it alive. It is found in puddles, ditches, ponds, lagoons, and the border of quiet lakes, especially during the warmer part of the summer. To hunt for it, tie a string, about 10 feet long, around the neck of a wide-mouthed bottle, toss the bottle into the water, and then pull it out. Hold the bottle between you and the light and look through it. *Volvox* is as large as a small pinhead and can be seen as rolling green globes (Fig. 148). The commonest species is called *Volvox globator*.

A colony of *Volvox* consists of thousands of cells, arranged in the form of a hollow sphere, with the green cells at the surface and the interior occupied by a soft gelatinous substance. Each cell is much like an individual of *Chlamydomonas*, with a chloroplast, pyrenoid, a nucleus, and two cilia. At first, all the cells are alike, but, as the colony gets older, there is vegetative reproduction and, later, gametic reproduction.

In vegetative reproduction one of the cells at the surface loses its cilia, enlarges a little, and divides. Each of the two new cells enlarges a little and this makes them crowd against their neighbors in the rim; the two cells divide again and the four resulting cells become crowded down beneath the surface of the rim, where they continue to divide until they form a young colony like the old one, but consisting of much smaller cells. When several young colonies have been formed in this way, they grow and are set free by the bursting of the old colony.

In gametic reproduction some cells become much larger than their neighbors but do not divide. They become filled with rich food substances and are called *eggs*. Other cells enlarge and divide, forming small colonies as in vegetative reproduction,

except that the cells are long and narrow and do not become so numerous as in the vegetative colony. The long narrow cells have two cilia and are called *sperms*. The whole group, or

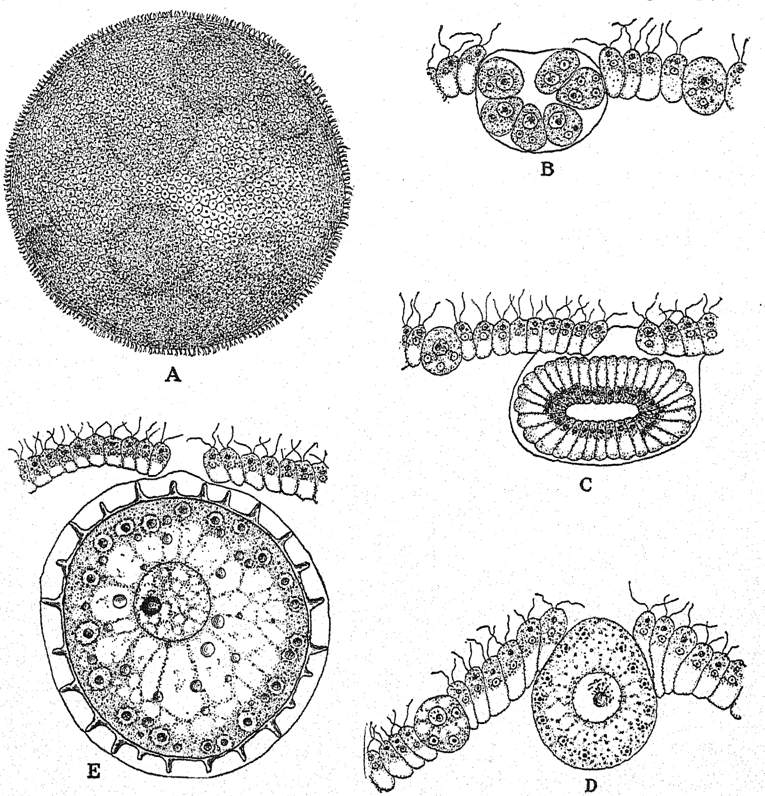


FIG. 148.—*Volvox*. *A*, mature colony with young colonies inside. *B*, young colony in rim of mature colony; at the right, a zoospore of the mature colony which has lost its cilia and is starting to form a new colony; *C*, a nearly mature antheridium; at the left, a zoospore which has lost its cilia and is starting to form an antheridium; *D*, an egg shortly before fertilization; at the left, a zoospore which has lost its cilia and is starting to form an egg; *E*, mature fertilized egg. The ciliated zoospores in *B*, *C*, *D* and *E* are in the rim of the mature colony. *A*, × 170, *B*, *C*, *D*, and *E*, × 780.

colony, of sperms is called an *antheridium*. The eggs and sperms are gametes. When the gametes are of different sizes, as in *Volvox*, the plant is said to be *heterogamous*—just another way of saying that the two gametes are different in size (Fig. 148). When the two gametes are alike, as in *Chlamydomonas*, the plant

is *isogamous*, the word meaning that the gametes are of the same size.

The sperm enters the egg and its nucleus unites with the nucleus of the egg. We give the name, fertilization, to the union of a sperm with an egg. The result is a zygote, but this zygote may be called a fertilized egg.

The wall of this zygote becomes very thick and warty. It sinks down into the mud and may rest for years before it starts to grow; but when conditions are favorable, a new colony begins to form, bursts the thick wall of the zygote, comes out, grows to the full size, and the life cycle is repeated.

Diatoms.—Everyone who uses a microscope is fascinated by the Diatoms, whether looking at them from a scientific standpoint, or merely for the sake of their beauty. They are microscopic in size and all of them are unicellular.

In hunting for Diatoms all sorts of places should be visited. If sticks and stones in the water are brownish and feel slippery, you can be almost sure of Diatoms. Rushes, stems of water plants, and submerged leaves which look brownish should receive attention. Surface mud of a pond or ditch will yield specimens. Put some of the mud in the bottom of a gallon battery jar, fill the jar nearly full of water, and put a black paper or cloth around it, so that the light will fall only on the surface of the water. Diatoms will come out of the mud and rise to the surface. Salt water forms may be secured by scraping oyster shells and barnacles. The big Strombus shell from the West Indies, which we sometimes use to keep the door open, and whose trumpet blasts were welcome sounds to the farmer boy at dinner time, will yield a good collection, if you get it before it has been cleaned. Since Diatoms are an important part of the food of marine fishes and other marine animals, their stomachs often contain deep sea forms which would be hard to get in any other way. Diatoms are an important part of the food of whales.

In geological times Diatoms were very abundant. Richmond, Va., is built on a layer of diatomaceous earth about 30 feet thick, and in some of our western states the deposits are even thicker. Some deposits contain about 40,000,000 Diatoms to the cubic inch. Most polishing powders, except sapolio, consist, principally, of Diatoms.

Scrape the brownish leaves or stems collected from ponds or ditches, add a drop of water and a thin cover glass, and examine with the microscope. Note the brown color and the movements. There is a brown coloring matter in addition to the green chloro-

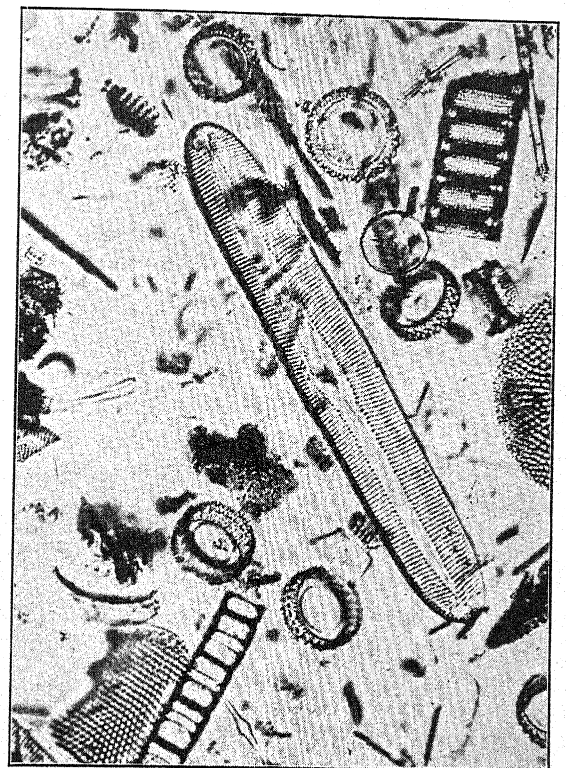


FIG. 149.—Diatoms. Diatomaceous earth from Cherryfield, Maine, of Pleistocene age. The largest diatom is *Pinnularia*. (*From a photograph by Miss Ethel Thomas, from a preparation by Rev. E. L. Little.* × 400. *From Chamberlain's "Methods in Plant Histology."*)

phyll. You will see something of the markings, but these are clearer in Diatoms which have been cleaned and mounted.

Some forms, including the very common *Pinnularia*, are shown in Fig. 149. The markings on Diatoms are often in the form of lines so delicate and so close together that there may be 5,000 of them to the millimeter, about 125,000 to the inch. In many cases the markings look like honeycomb.

The cell division, in most cases, is very peculiar. The cell wall is in two pieces, one fitting over the other like the lid on a box. Consequently, as division after division takes place, the

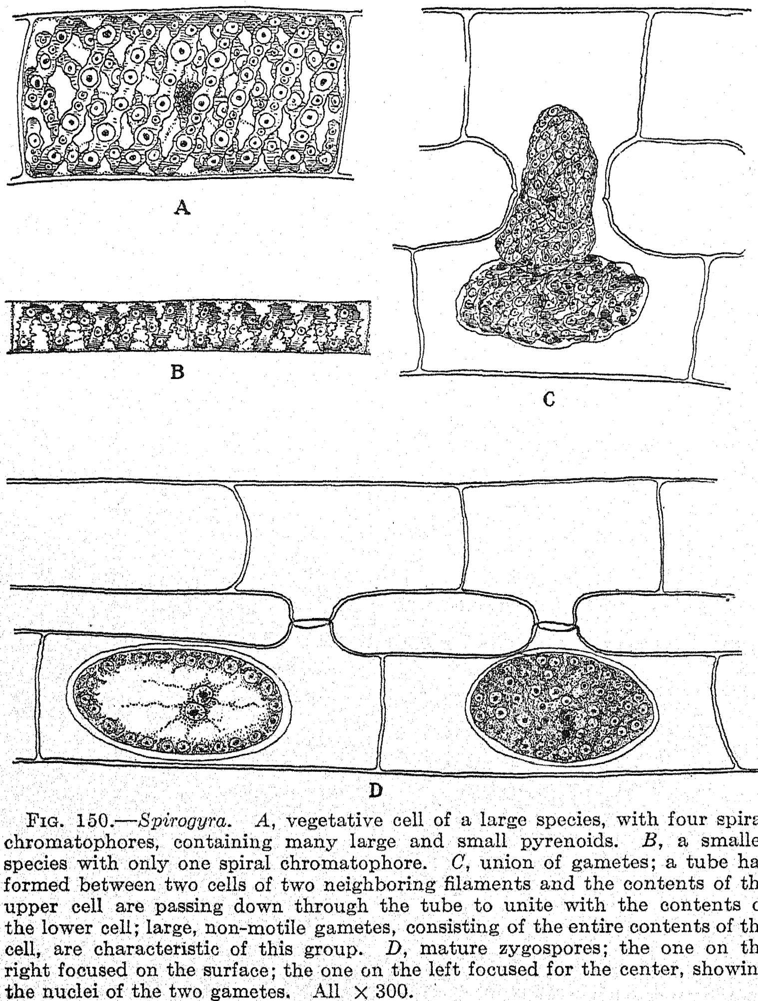


FIG. 150.—*Spirogyra*. *A*, vegetative cell of a large species, with four spiral chromatophores, containing many large and small pyrenoids. *B*, a smaller species with only one spiral chromatophore. *C*, union of gametes; a tube has formed between two cells of two neighboring filaments and the contents of the upper cell are passing down through the tube to unite with the contents of the lower cell; large, non-motile gametes, consisting of the entire contents of the cell, are characteristic of this group. *D*, mature zygospores; the one on the right focused on the surface; the one on the left focused for the center, showing the nuclei of the two gametes. All × 300.

Diatoms get smaller and smaller. Finally, two Diatoms come together, the lids come off the boxes, and the protoplasm comes out. The two masses of protoplasm unite, forming a zygote

which grows immensely and forms a new wall. In this way the original size is restored.

Cell division and formation of the zygote are so difficult to recognize that even classes in universities see little of these features.

Spirogyra.—No other alga is so widely known as *Spirogyra.* The beautiful green spiral bands, the chloroplasts, which contain the chlorophyll and pyrenoids, give it such a characteristic appearance that you recognize it immediately, if you have seen a picture of it (Fig. 150).

Spirogyra occurs in the form of yellowish green mats on the surface of ponds, ditches, and any other quiet water. Masses of it below the surface have a brighter green color and are more slippery than the floating mats.

When it is reproducing, tubes are formed between the cells of neighboring filaments, so that the two filaments, with the tubes between them, make a microscopic ladder. The cell contents shrink away from the wall and the entire contents of one cell slip through the tube into the neighboring cell. The shrunken cell contents are two gametes which unite to form a zygote, usually called a zygospore.

The zygote, whose wall becomes quite thick, withstands the cold of winter or the drying up of the pond, and the next spring it grows out into a new filament. The two gametes have no cilia and do not swim, and so they are called non-motile gametes. Since there are no zoospores, like those of *Chlamydomonas*, and no resting cells, like those of the Blue Green Algae, this life history has only gametic reproduction.

Ulothrix.—*Ulothrix* is a very instructive alga, especially if living material can be secured (Fig. 151). It grows attached to sticks and stones in riffles of brooks and rivers, and also on piles and rocks along the borders of lakes or large ponds where waves are constantly dashing, but it is seldom found in quiet water. It appears and disappears three or four times during a season. *Ulothrix* is silky and very slippery, growing in dark green tufts, usually not more than two or three inches long, and often shorter.

It has zoospores and gametes, both swimming vigorously by means of cilia. There are also resting cells. The zoospores,

after swimming awhile, settle down and grow into new filaments. The gametes unite in pairs, forming a zygote, which may grow at once into a new filament, or may form a thick wall and rest for a long time. When the resting period is over, the zygote grows into a new filament; but sometimes, after resting awhile, it produces four zoospores, each of which grows into a new filament.

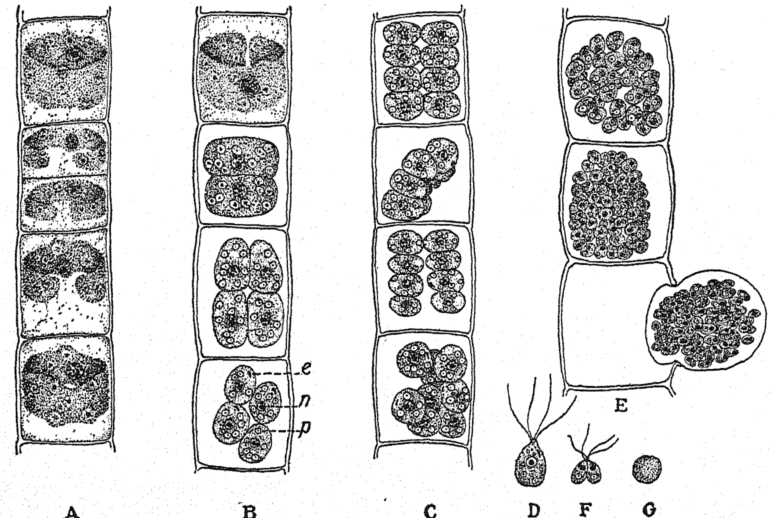


FIG. 151.—*Ulothrix*. *A*, part of vegetative filament with five vegetative cells. In the top and bottom cells, the chromatophore is shaped like a napkin ring; in the other three, the ring is not quite closed; the second and third cell from the top have just been formed by a vegetative division. *B*, a vegetative cell at the top; the cell below has divided and one more division would make four zoospores; the next cell shows four young zoospores, and the bottom cell shows four zoospores almost ready to escape; each zoospore has a nucleus, *n*; several pyrenoids, *p*; and an eyespot, *e*. *C*, four cells, each with eight nearly mature zoospores. *D*, a mature zoospore. *E*, filament with gametes; the upper cell has 32 nearly mature gametes; the middle cell, 64; and the lower, 64, which are escaping. *F*, two gametes uniting. *G*, zygote formed by the two uniting gametes. All × 535.

In a single collection, one often finds filaments of different sizes, because one, two, four, or eight zoospores are formed in a cell and these zoospores, of different sizes, produce filaments of different sizes.

Oedogonium.—*Spirogyra* and *Ulothrix* grow in such conspicuous masses that they are easy to find; but *Oedogonium* might escape notice. Many species grow attached to dead or living twigs or grasses under water, forming a fuzzy coating of short

unbranched filaments, often not more than a quarter of an inch in length. Some species grow on mosses under water and a few form dense floating mats which look like *Spirogyra*.

The cells of the vegetative filament are all alike, but the reproductive cells are very different (Fig. 152).

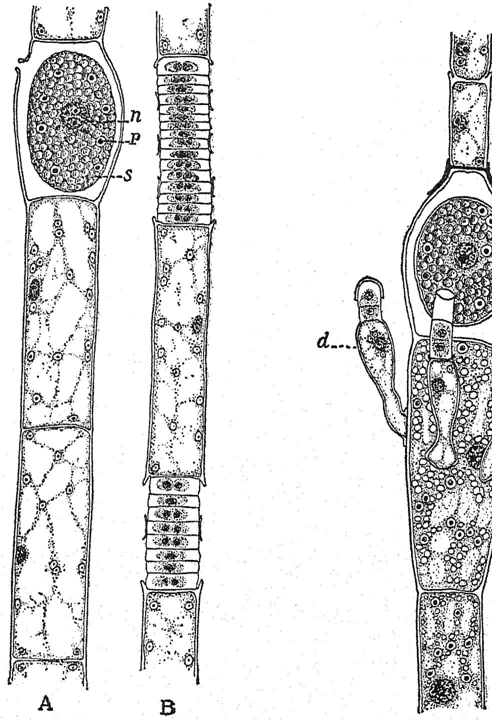


FIG. 152.—*Oedogonium*. *A* and *B*, a dioecious species. *A*, oogonial filament showing two vegetative cells and an oogonium containing a fertilized egg: *n*, nucleus; *p*, pyrenoid; *s*, starch. *B*, antheridial filament with two groups of antheridia, the upper group with 16 antheridia, the lower with eight. Most of the antheridia contain two nearly mature sperms. *C*, a species with dwarf males, *d*, attached to the cell below the oogonium; the dwarf male on the left has two nearly mature sperms; the one in the middle has two antheridia, the upper one of which has discharged its sperms; in the dwarf male at the right, one sperm has escaped from the upper antheridium and the other is nearly out. All × 300.

Here and there in the filament a cell swells immensely and the contents shrink away a little from the wall and round off into a sphere, which is called the egg. The cell which contains the egg is called the *oogonium*. Other filaments, or the same

filament, have short cells mixed in with the longer vegetative cells. These short cells are *antheridia,* and each one of them produces two sperms. A sperm enters the egg and their two nuclei unite. This union is called *fertilization.* The fertilized egg may germinate at once or it may rest for years; but, finally, it produces four zoospores which, at first, are contained in a colorless sac, but soon escape and grow into new *Oedogonium* plants. A study of Fig. 152 and such stages in the life history as you may be able to find will enable you to understand this alga. In many species, like the one shown in Fig. 152*C*, the life history is not so simple as the one described here.

Chara.—The name, Stonewort, is sometimes given to *Chara* because it contains so much lime. In Part I the common name was the only one given; but in these lower forms either there are no common names at all or there is no uniformity in the use of such names. Where a common name is in general use, it will be placed first; but where there is no generally accepted common name, the scientific name will be used.

Chara grows on sandy or clay bottoms of ponds, ditches and lagoons. It is a coarse, rough, brittle plant, often a foot or more in length, branching freely and is usually covered with oogonia and antheridia (Fig. 153). Some species have a bad odor—one of them is called *Chara foetida*—and in water reservoirs the whole group is troublesome.

The whole plant is built up by repeated divisions of a conspicuous cell at the apex.

The oogonia are surrounded by spirally twisted filaments. When young, they are green, but, after fertilization, they become black. When the fertilized egg germinates, it produces a short, unbranched filament, from which the new *Chara* plant originates as a side branch.

The antheridium is the most complicated one in the whole plant kingdom. It has an orange red color when ripe and contains a large number of long filaments, each filament having about 200 cells, each cell containing a sperm.

Other Green Algae.—If you collect algae from ponds, ditches, and other places, you will find many besides the ones which have just been described, especially unicellular forms and small multicellular forms which cannot be seen without a microscope.

They are frequently mixed with *Oscillatoria* and other Blue Green Algae and even with colorless microscopic animals, which have cilia and move about as freely as zoospores or gametes of algae. Some of the forms you are almost sure to meet are shown in Fig. 154.

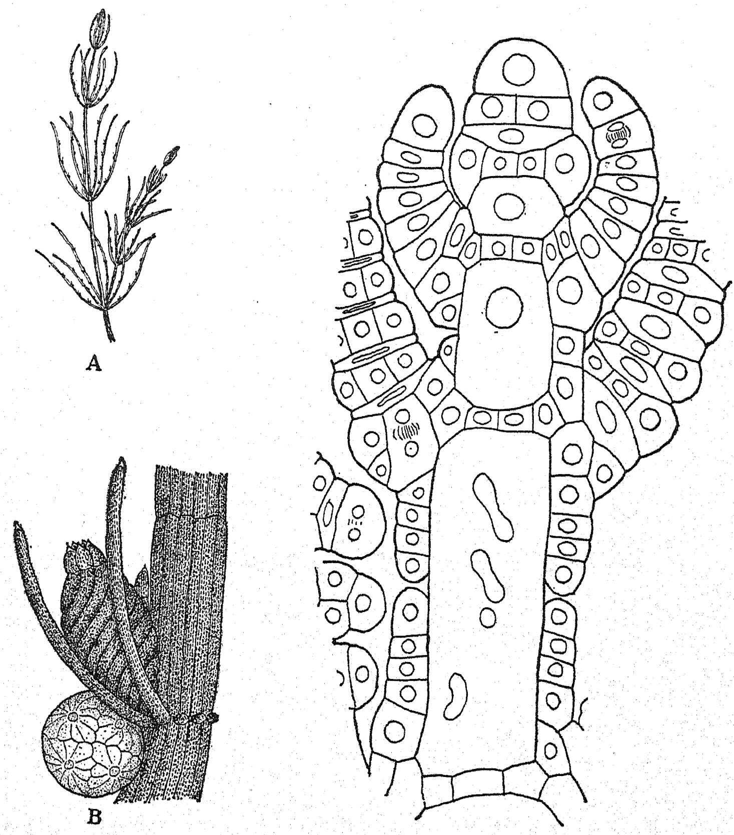


FIG. 153.—*Chara.* *A*, habit sketch, about natural size. The dots on the branches are the oogonia and antheridia. *B*, an oogonium with its spiral bands and, below it, a spherical antheridium. *C*, section of the tip of a plant showing the very regular development from an apical cell. $\times 270$.

General Remarks on Green Algae.—The lower members of the Green Algae are unicellular, but most of the higher forms are filamentous. Some of the filamentous forms branch and some do not. A few occur in the form of thin plates.

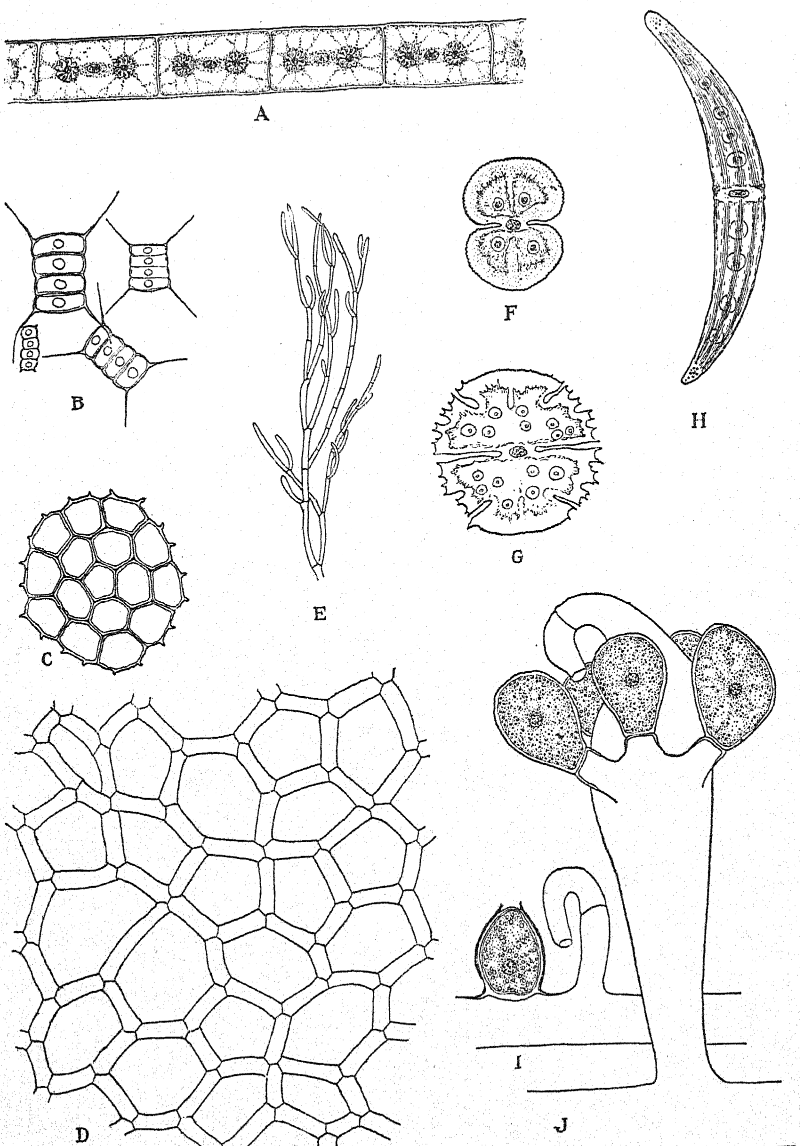


FIG. 154.—Some common green algae. *A*, *Zygnema*, × 245; *B*, *Scenedesmus*, × 535; *C*, *Pediastrum*, × 535; *D*, *Hydrodictyon* (Water Net), × 33; *E*, *Cladophora*, × 33; *F*, *Cosmarium*; *G*, *Micrasterias*; *H*, *Closterium*; *F*, *G*, and *H* are Desmids, × 535; *I*, *Vaucheria sessilis*, and *J*, *Vaucheria geminata*; both × 150.

Many have reproduction by zoospores; many have resting cells; and many have gametes. Isogamous gametes are lower in the scale of development than heterogamous gametes. Heterogamy is more efficient because the large food supply in the egg enables it to develop farther before it must depend upon outside sources for food. That isogamy is not so successful is shown by the fact that this method is not found in any plants above the Thallophytes.

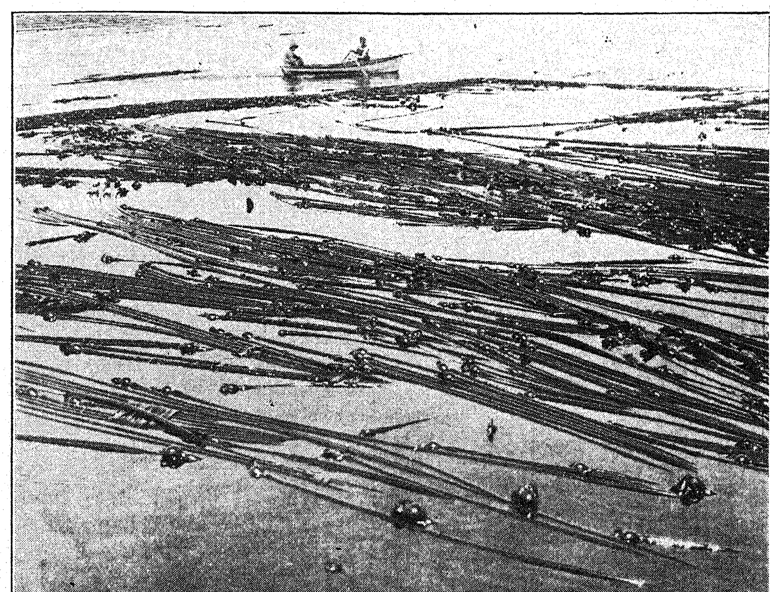


FIG. 155.—*Nereocystis lütkeana* at the Puget Sound Biological Station, near Friday Harbor, Washington. The bulb and upper part of the plant float on the water, but the leaves and most of the stalk are below the surface.

Brown Algae (Phaeophyceae).—*Phae-* means brown and *-phyc-* means alga, so here again the common name is merely the translation of the scientific name.

The Brown Algae grow in salt water along the coasts of the ocean and salt-water seas and lakes. They are often torn loose by storms and carried hundreds of miles out to sea; and some of them are found in rivers, several miles from the sea, where tides drive salt water into the river channels.

None of them are unicellular, but many are filamentous, and the group is famous for the immense size of some of its members (Fig. 155). *Nereocystis*, on our Pacific Coast, often reaches a length of 100 feet and sometimes even 150 feet. It has a holdfast, a long stalk the upper part of which floats upon the water and ends in a big bladdery bulb bearing numerous leaves hanging down below the surface. Students sometimes carve dolls from the big bulbs. A couple of these carved bulbs, one with the leaves turned back and the other with the leaf blades cut off, might pass for "Maggie and Jiggs" (Fig. 156).

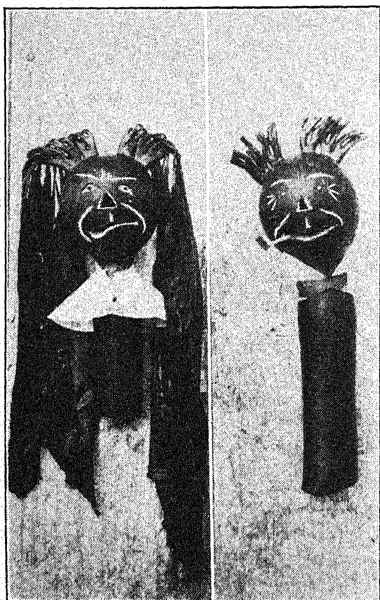


FIG. 156.—*Nereocystis lütkeana.* Bulbs carved to represent "Maggie and Jiggs." At the left, the lower part of the leaf blades are shown; at the right, the blades have been cut off, leaving only the stalks. These bulbs are about as large as a man's fist.

Macrocystis, on the California Coast, sometimes reaches a length of 150 feet. *Pelagophycus*, the Sea Alga, often torn loose and thrown up on California beaches, has a bulb almost as large as one's head. Various other members reach a length of 20 or 30 feet, and there are many other coarse forms 1 or 2 feet in length.

Most forms produce both zoospores and gametes, but some produce gametes only. When motile, both zoospores and gametes are bean shaped and have their two cilia on the side instead of on the end, as in the Green Algae.

Ectocarpus.—*Ectocarpus* is a typical representative of the lower filamentous members of the Brown Algae (Fig. 157). It grows on various larger algae, forming dense tufts of branching filaments a few inches in length. It grows all the year round, forming zoospores during the colder part of the year and gametes during the warmer season.

The sporangia are at their best in the winter. They are spherical or somewhat elongated and contain many zoospores. When the zoospores escape, they swim about for a while, then come to rest on some suitable object and grow immediately into new branching plants.

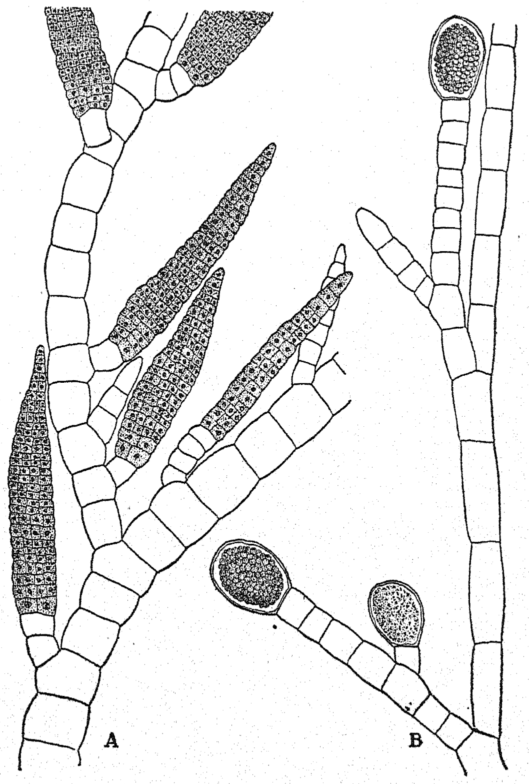


FIG. 157.—*Ectocarpus*. *A*, a small portion bearing gametangia; *B*, December condition, with sporangia. × 300.

The gametangia are much longer and consist of a large number of very small cells in each of which a gamete is formed. The gametes escape and unite in pairs, forming zygotes which germinate immediately and form branching plants like those coming from zoospores. Since the gametes are generally of the same size, *Ectocarpus* is isogamous (Fig. 157).

Laminaria.—*Laminaria* belongs to a group of coarse leathery Brown Algae, called Kelps or Devil's Aprons. It is a coarse leaflike alga attached to stones or shells by a conspicuous *holdfast.* Above the holdfast is a stalk which broadens out into a broad blade (Fig. 161*B*).

On the blade, sporangia are formed in large patches with thousands of sporangia in a patch. Each sporangium produces a large number of zoospores, some of which produce short fila-

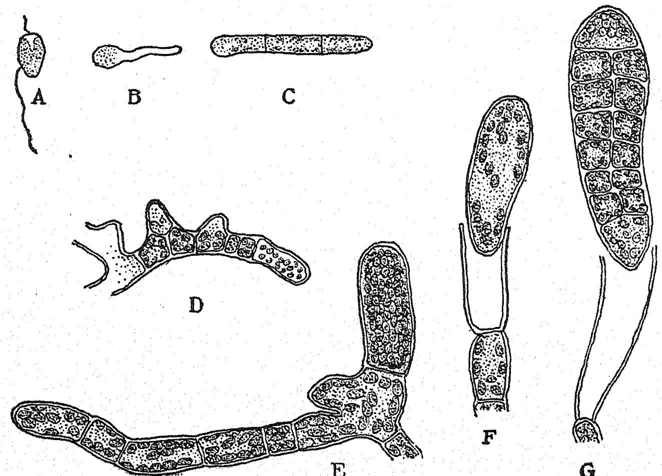


FIG. 158.—*Costaria costata.* *A*, zoospore, × 760; *B*, one-celled filament from germinating zoospore; *C*, three-celled filament; *D*, older filament with two antheridia; *E*, filament with an oogonium containing one egg; *F*, fertilized egg escaping from oogonium; *G*, young sporophyte developing from fertilized egg. This young sporophyte, scarcely visible to the naked eye at this stage, may reach a length of 6 feet. *B, C, D, E, F*, and *G*, × 320. (*After Miss Laura Angst.*)

ments bearing antheridia, and some produce filaments bearing oogonia. A sperm from the antheridium fertilizes the egg in the oogonium and the fertilized egg at once begins to grow into a big plant. So the big plant bears spores which produce microscopic filaments bearing eggs and sperms. A sperm fertilizes an egg, which then grows until it becomes a big plant. Thus the big plant produces the little one, and the little one produces the big one. The big plant and the little one *alternate.* This is *Alternation*[1] *of Generations.* The big plant, since it bears

[1] Look in the dictionary for pronunciation of *alternation.* It is almost always mispronounced.

spores, is called the *sporophyte* (spore bearing generation); and the little one, since it bears gametes, is called the *gametophyte* (gamete bearing generation).

The life history is about the same in *Costaria*, from which the illustrations are taken of zoospores and gametophytes with their antheridia, oogonia and young *Costaria* plants (Fig. 158).

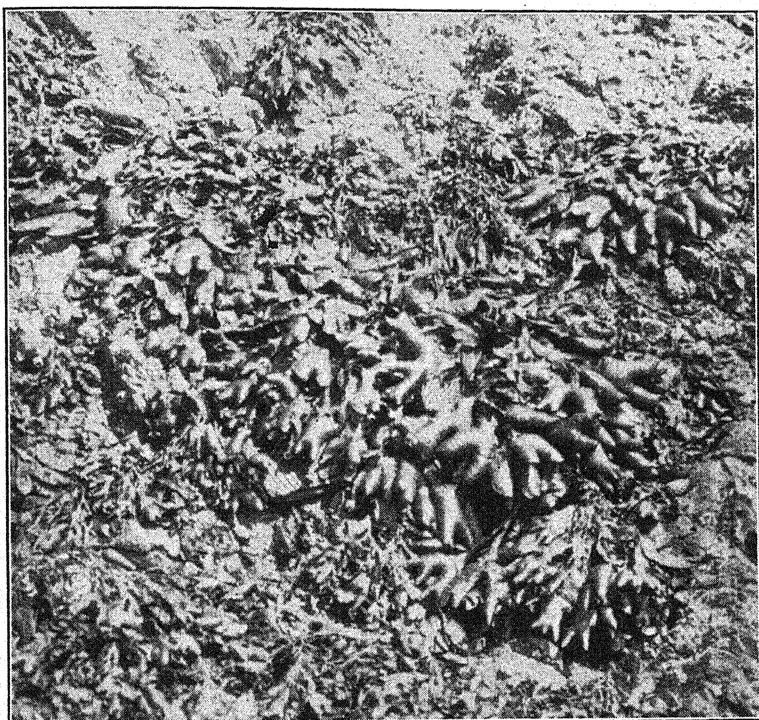


Fig. 159.—*Fucus evanescens.* At low tide at the Puget Sound Biological Station.

The gametophytes are scarcely visible to the naked eye; but the sporophytes of both *Laminaria* and *Costaria* often reach a length of six feet (Fig. 161).

Fucus.—*Fucus* is the best known and most widely distributed of all the Brown Algae. It is about a foot long, seldom more than two feet long, but it occurs in great masses on rocks which are covered and uncovered by the ebb and flow of the tides (Fig. 159). The girdle of *Fucus*, covered at high tide and

exposed at low tide, is a conspicuous feature of the ocean life of temperate and colder regions. During storms great quantities of *Fucus* are torn loose and thrown upon the beach, making it easy to collect material. Since the alga is tough and is covered with mucilage, it can be rolled up in newspaper and sent a

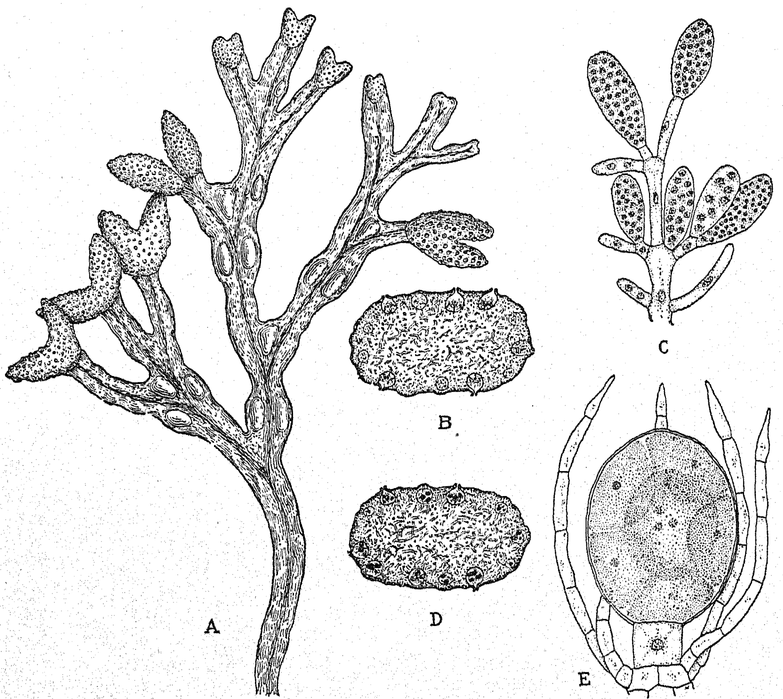


FIG. 160.—*Fucus vesiculosus*. *A*, habit, one-half natural size; *B*, cross-section of fruiting tip showing antheridial conceptacles, × 3; *C*, small portion from a branching filament from an antheridial conceptacle, showing six antheridia, × 480; *D*, cross-section of a fruiting tip with oogonial conceptacles, × 3; *E*, oogonium with eight nearly mature eggs, × 225.

thousand miles by parcel post and arrive in fine condition for study. The individual plant is coarsely ribbon like, branches profusely, and, when fruiting, has the swollen tips of its branches covered with *conceptacles*. The conceptacles appear on the surface as small warty elevations easily seen without a lens. They contain oogonia or antheridia. Besides, there are much

smaller dots scattered over the whole surface. These are called hair pits and there is hardly any doubt that they were originally conceptacles and that the ancestors of *Fucus* had conceptacles all over the surface. In fact, some living relatives of *Fucus* have conceptacles all over the surface. In some species of *Fucus*, there are air bladders which keep the plant erect when it is covered with water. The one shown in Fig. 160 is called *Fucus vesciculosus* on account of the air bladders.

In *Fucus vesiculosus*, some plants have conceptacles containing only oogonia, while in other plants they contain only antheridia; and so the species is dioecious, the eggs and sperms being produced by different plants. In some species, a plant will have some conceptacles producing oogonia and others producing antheridia; and in still other species, oogonia and antheridia are produced in the same conceptacle. A single antheridial conceptacle contains hundreds of antheridia, and each antheridium contains 64 sperms which, when mature, escape through the pore at the top of the conceptacle (Fig. 160*B*, *C*).

A single oogonial conceptacle contains many oogonia, and each oogonium contains eight eggs which, when mature, escape through the pore at the top of the conceptacle and float in the slime which is very abundant there (160*D*, *E*).

The sperms swim in the slime in such great numbers that they roll the eggs about until one sperm enters the egg and its nucleus unites with the nucleus of the egg. The fertilized egg at once begins to divide and soon develops into a *Fucus* plant.

Some Common Brown Algae.—Some Brown Algae which one is likely to meet are shown in Fig. 161. *Costaria* gets its name from its riblike veins; *Agarum*, with its numerous holes, is like a sieve; *Cymathere* is like *Laminaria*, except that it has three folds in the center of the blade; *Alaria* is named for the winglike leaves at the bottom, which are called sporophylls because they bear the sporangia; *Chorda* is like a long cord, not so large around as a lead pencil but often 5 or 6 feet in length and, in the English Channel, specimens have measured 20 feet in length. They are quite strong and fishermen call them Mermaids' Fish Lines. *Dictyota dichotoma* is somewhat smaller than *Fucus*. Its branching is very regularly forked. Along our western coast

from Alaska to San Diego, there are many large Kelps. The largest Algae in the world are on our Pacific Coast. All of

FIG. 161.—Some common Brown Algae. *A*, *Chorda*, ¼ natural size; *B*, a very small *Laminaria*, ½ natural size; *C*, *Ascophyllum*, ½ natural size ; *D*, *Sargassum*, natural size; *E*, *Dictyota*, natural size; *F*, *Costaria*, small plant ¼ natural size.

these forms are related to *Laminaria* and have similar life histories.

Ascophyllum, named from its swollen bladders, is about as large as *Fucus*. In the eastern and middle states this is the alga which is packed about fish coming from the Atlantic Coast. *Sargassum* is found in temperate waters but reaches its best farther south, where detached masses reproduce while floating. In the tropics west of the West Indies such immense masses are found floating that the region is called the Sargasso Sea. *Sargassum* has leaves looking like leaves of flowering plants and its air bladders look so much like berries that the sailors of Columbus were encouraged to believe they were nearing land.

Ascophyllum, Sargassum, and several other algae of about the same size are related to *Fucus* and have similar life histories (Fig. 161).

Red Algae (Rhodophyceae).—*Rhod-* means red and *-phyc-* means alga, so Rhodophyceae means Red Algae. Nearly all of them are red because they have a red pigment in addition to the green chlorophyll, and the red is so abundant that it obscures the green. A few members of this group live in fresh water and have no red pigment. They are green like the Green Algae but are distinguished from them by their structure.

Many of the Red Algae are very beautiful. The group used to be called the Florideae, because they have the colors of flowers. Florida got its name from its beautiful flowers. Red Algae are often called *Sea Mosses*, because so many of them have a delicate, mosslike outline. These are the ones we press for postal cards and fancy letter heads and even to frame like pictures.

The Red Algae are at their best in warmer waters and become scarce in colder seas. As a group, they grow in deeper water than the Brown Algae, but it is not uncommon to find Blue Green, Green, and Red Algae growing on some Brown Alga, like *Fucus*.

There are no unicellular forms and no very large ones. Most of them are less than a foot high and very few of them reach a height of two feet.

There are no isogamous members; all are heterogamous, a large cell which might be called an egg, but which is called a *carpogonium*, being fertilized by a small non-motile sperm.

In a few of the simpler Red Algae, like *Nemalion*, reproduction can be studied without much difficulty; but in most of the group

the process is so complex that very carefully selected material and very skillfully prepared sections are necessary for any study of details.

Nemalion.—Nemalion is pink or reddish, looking like a mass of slender slippery worms hanging down from the rocks at low tide and floating weakly and partly erect when the tide comes in. It is about one-sixteenth of an inch in diameter but often reaches a foot in length, usually branching a little but never profusely (Fig. 162).

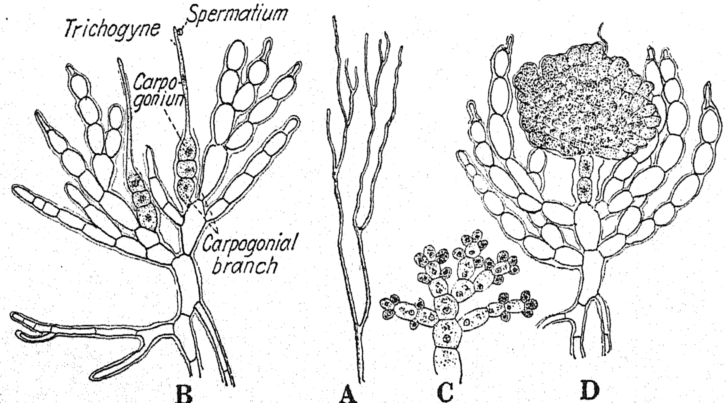


FIG. 162.—Nemalion. *A*, part of plant, one-half natural size. *B*, two carpogonia, each with a long slender trichogyne; the *carpogonia* and the two cells under each carpogonium are shaded. × 300. *C*, part of an antheridial branch bearing several nearly sperical antheridia. × 600. *D*, cystocarp consisting of many carpospores. × 300.

The wormlike thread is not a single row of cells but is made up of a large number of filaments, each consisting of a single row of very slender cells, branching at the tip, where the cells are much larger. When the plant is in fruit, as it usually is, these larger cells bear antheridia or carpogonia, both on the same plant.

The carpogonium is narrowed above into a long neck called the *trichogyne;* and, below, rests upon three or four or more flattened cells called the *carpogonial branch.* The carpogonium and trichogyne, together, are called the *procarp* (Fig. 162*B*).

An antheridial branch bears numerous antheridia, which are usually called *spermatia.* They are not sperms, for each one

contains two nuclei, one of which is the sperm nucleus. The spermatium, which is non-motile in all the Red Algae, comes to rest on the tip of the trichogyne and one of its nuclei moves down and unites with the nucleus in the carpogonium.

The whole carpogonium then behaves like a fertilized egg, dividing and dividing until it has produced several chains of cells, the end cell of each chain being a *carpospore,* which at once develops into a new *Nemalion* plant. The trichogyne

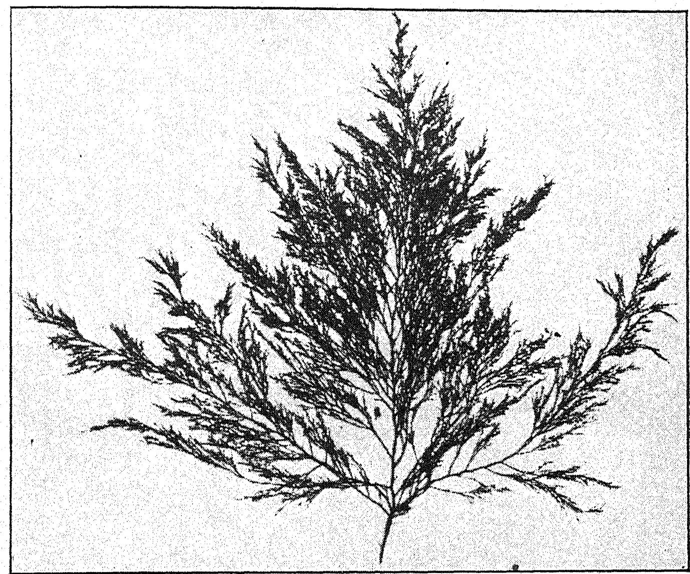


FIG. 163.—*Polysiphonia.* Photo, natural size.

begins to wither as soon as the fertilized carpogonium begins to divide. The whole mass of cells produced by the carpogonium is called a *cystocarp.* A study of the various stages shown in Fig. 162 should make this life history clear.

Botanists have worked out many life histories in the Red Algae, but nearly all of them are much more difficult to study than that of *Nemalion.*

Polysiphonia.—The most thoroughly studied member of the Red Algae is *Polysiphonia* (Fig. 163). It is rather abundant in shallow water on both our Atlantic and Pacific coasts and it is

easily recognized. Consequently, it is very much studied in classes, in spite of the fact that details of its life history are very difficult to follow.

A few features, however, can be seen without much difficulty (Fig. 164).

There are three plants in the life history, one bearing antheridia and one bearing carpogonia which develop into cystocarps after fertilization. The carpospore develops into a third kind of

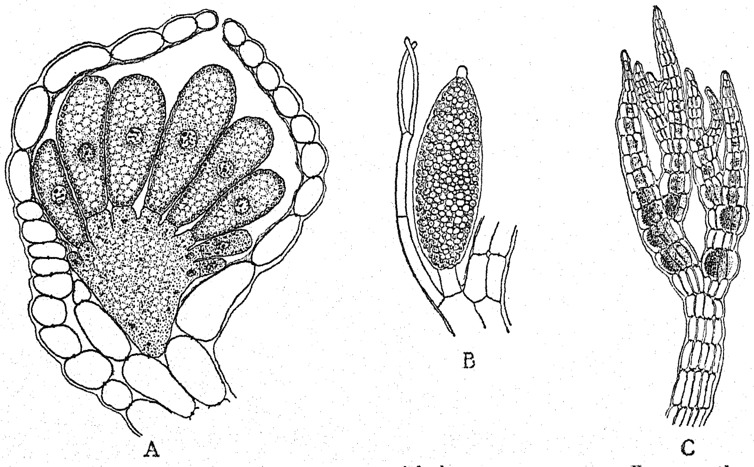


Fig. 164.—*Polysiphonia.* *A*, cystocarp with large carpospores; *B*, an antheridium; *C*, tetrasporic branch with tetraspores. *A* and *B*, × 240; *C* × 30.

plant bearing spores in fours, so that the groups of four are called tetraspores. Half of the tetraspores produce plants bearing antheridia, and the other half produce plants bearing carpogonia.

The big cell bearing the carpospores is formed by the union of several helping (auxiliary) cells.

Other Red Algae.—Some other Red Algae which you may meet on our Atlantic or Pacific coasts are shown in Fig. 165.

Chondrus, a rather stiff, profusely branching alga, a few inches in height, grows in great abundance on the North Atlantic coasts. It is the "Irish Moss" of commerce and is used in making jellies. In Japan it is cut into small pieces and mixed with clay for plaster. Such plaster, with a little straw, does not crack, even when there is a slight earthquake.

A plant of *Delesseria* looks like a small branch of a flowering plant, except that it is red. One species looks like a cluster of Oak leaves.

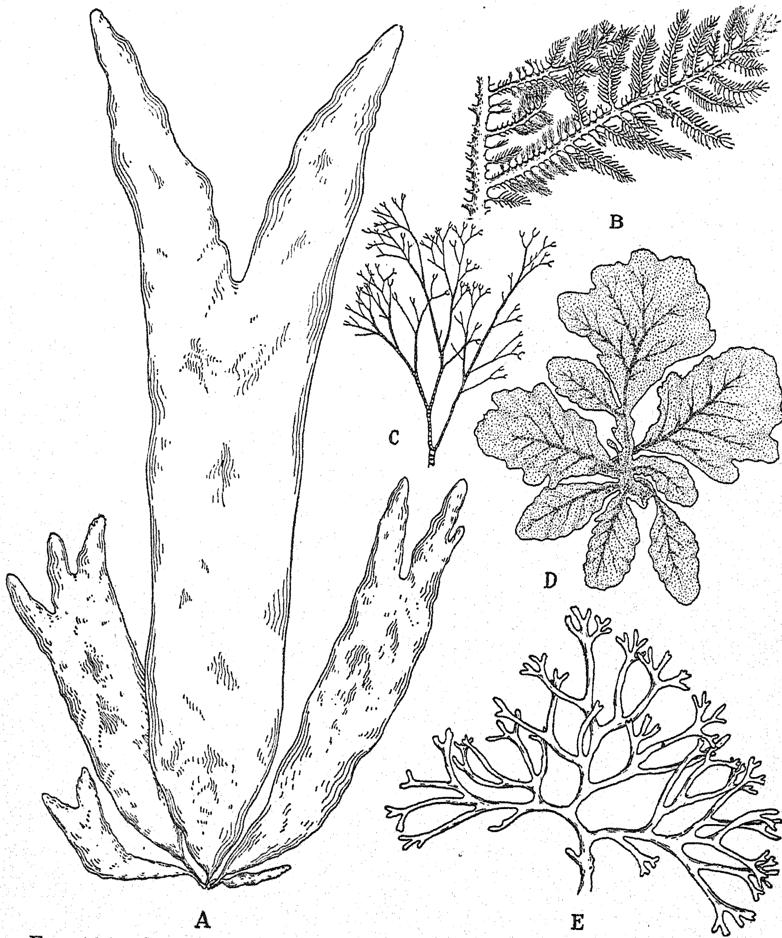


FIG. 165.—Some common Red Algae. *A*, *Rhodymenia palmata*, one-third natural size; *B*, *Plumaria elegans*, × 5; *C*, *Ceramium rubrum*, natural size; *D*, *Delesseria sinuosa*, one-half natural size (*after Harvey*); *E*, *Chondrus crispus*, one-half natural size.

Ceramium is one of the most widely distributed of all the Red Algae. You are sure to find it, if you make any collections at

the seashore. It is usually not more than a couple of inches in height, but its bright red color and delicate branching make it a favorite form to float out and mount on cards.

Plumaria gets its name from its resemblance to a feather. It is usually only an inch or so in height, but, like *Ceramium*, it is a beautiful form to mount on souvenir cards or letterheads.

Corallina usually has a pale pink color because it is so incrusted with lime that the color beneath is obscured. Masses of Corallina help build up coral reefs, just as if they were real corals. Naturally, the stony covering keeps its form after the plant dies. Algae, closely resembling the *Corallina* of today, have been found in the geological age called the Cambrian, which geologists say must date back more than a hundred million years. Other algae must have been much older, but soft delicate forms have left no record in the rocks.

CHAPTER X

THALLOPHYTES

FUNGI

The Fungi are those Thallophytes which have no chlorophyll. They are usually colorless, but some of them have striking colors —blues, greens, browns, yellows, reds, and various others— but since there is no chlorophyll, the Fungi are entirely unable to manufacture food from inorganic material. They live upon other plants or animals.

If they grow upon living plants or animals, we call them *parasites*. The *para-* means beside and the *-site* means to sit. The word was originally applied to a person who *sat at the table beside* some one else who paid all the bills. The meaning is the same here. Parasites get their food from the plants and animals upon which they grow, causing various diseases and often killing their hosts; but some parasites not only do no harm but are even beneficial.

If the fungus grows upon dead or decaying animals or plants, it is called a *saprophyte*. Some fungi can grow upon either living or dead hosts.

Myxomycetes.—The Myxomycetes are seldom studied by beginners, but they should at least be mentioned. Some people who have studied them believe that they are animals, while others who have studied them just as thoroughly believe that they are plants. It is worth while, even as a matter of curiosity, to see what they look like.

They are very small, only a few reaching the size of a Walnut. Many are slender and delicate, less than half an inch in height; but most of them are smaller, about the size of a pinhead.

Many of them grow on rotten logs or sticks, especially down near the ground on the shaded side. They are found throughout the year, except in winter where winters are cold. The best time to look for them is two or three days after a rain.

Fuligo.—Since this is the largest of the Myxomycetes, it is not so likely to escape notice as the smaller ones (Fig. 166). Look for it on Oak stumps, on tanbark, and on piles of sawdust.

Stemonitis.—Stemonitis is likely to be found wherever there are any Myxomycetes at all (Fig. 167). It grows in beautiful little brownish tufts not quite half an inch high. There is a slender shining black stalk extending up into a spore case filled with very small dark spores.

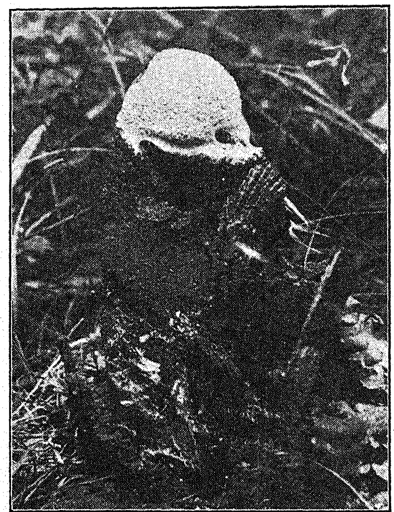


FIG. 166.—*Fuligo.* The largest Myxomycete, one-half natural size. (*From a photograph by Miss Ethel Thomas.*)

Trichia.—*Trichia* is much smaller, not larger than a pinhead, and some species of it are not so large as a Mustard seed; but it has a bright yellow color and hundreds of them grow crowded together, so that it is not difficult to find (Fig. 167).

As it ripens, the spore case (sporangium) breaks and a tangle of threads and spores comes out. The threads are beautifully marked with spiral bands, which can be seen only under a rather high power of the microscope.

Lycogala is a common Myxomycete, about as large as a Pea, with a delicate red color while young and a beautiful bronze color as it becomes mature (Fig. 167*F*).

What we have described up to this point is the plantlike part of the life history. A sporangium producing spores is very characteristic of plants; but when the spores germinate, they produce naked masses of protoplasm which can hardly be distinguished from the *Amoeba* of the zoologist. Great numbers of these Amoeba-like individuals flow together and form a common mass of protoplasm, which is called a *plasmodium.* The Amoeba stage and the plasmodium resemble some of the lower animals. After a time the plasmodium develops into the spo-

rangium stage. During a part of its life history the Myxomycete behaves like a plant, and during the rest of it, behaves like an animal. Most of the studies on Myxomycetes have been made by botanists.

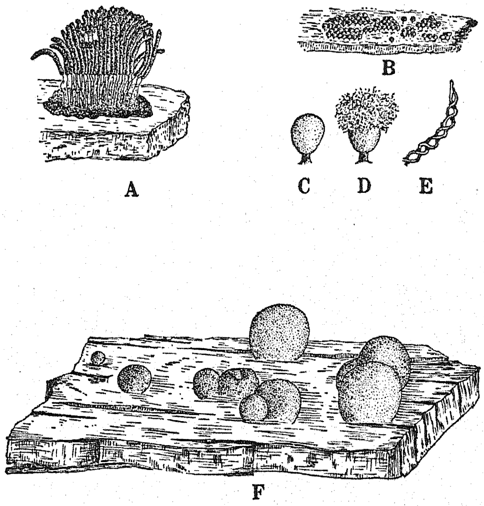


FIG. 167.—Other Myxomycetes. *A*, *Stemonitis* one-half natural size. *B*, *C*, *D*, and *E*, *Trichia*, a small Myxomycete. *B*, group of sporangia natural size. *C*, a single sporangium, × 7. *D*, the sporangium has burst and the thready capillitium is coming out, × 7. *E*, part of a thread of the capillitium, showing spiral markings, × 250. *F*, *Lycogala*, a very large Myxomycete; its plasmodium and young sporangia are red, but mature sporangia have a rich bronze color. Natural size.

Schizomycetes (Bacteria).—The Bacteria are studied so thoroughly in medical schools that some might imagine Bacteria are animals. There is no uncertainty here, however, as there might be in case of the Myxomycetes. The Bacteria are plants.

There is no difficulty in getting material. They appear where they are not wanted and the difficulty comes in getting rid of them.

Bacteria are everywhere—in the air, in the soil, and in water. A poorly ventilated schoolroom is full of them and even a well-ventilated room has some. There are more of them at recess than there were when school began in the morning. There are many Bacteria in the soil, especially if the soil is rich with decaying leaves and other organic matter. Water without any

Bacteria is rare. Pure spring water and water from deep artesian wells may be free from them at first, but if a pitcher of such water is exposed to the air for a few minutes, the Bacteria get a start. Water from lakes and reservoirs is pretty good; but water in rivers which flow past cities, exposed to sewage and all kinds of

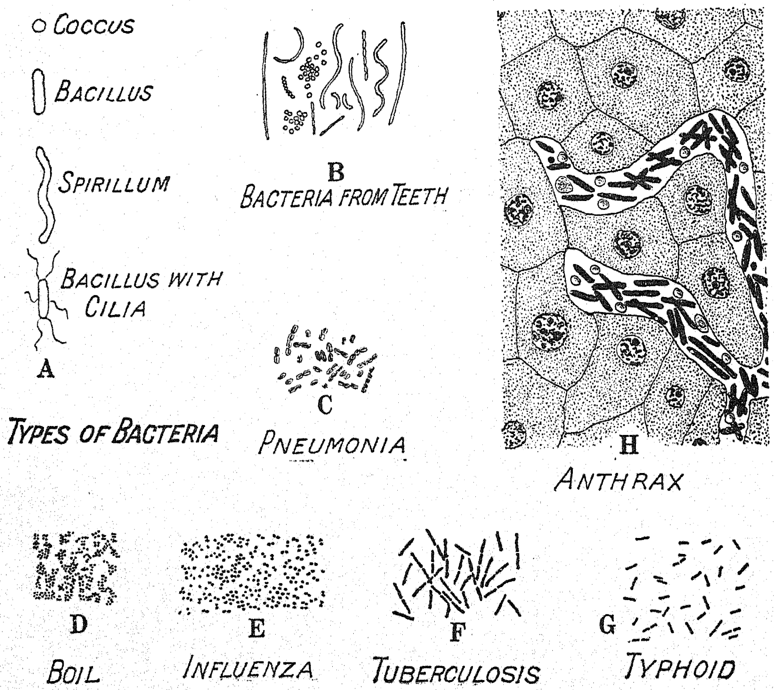


Fig. 168.—Bacteria. *A*, diagrams of types of bacteria; *B*, *Coccus*, *Bacillus*, and *Spirillum* forms scraped from healthy teeth; *C*, the germs which cause pneumonia, showing the gelatinous covering; *D*, a *Coccus* form taken from a boil; *E*, the *Coccus* form which causes influenza; *F*, the *Bacillus* which causes tuberculosis, *G*, the *Bacillus* which causes typhoid; *H*, Anthrax, a very large *Bacillus* in the liver of the mouse. All of the bacteria, *B*, *C*, *D*, *E*, *F*, *G*, and *H*, are drawn to the same scale. × 720.

contamination, is the worst. It should always be boiled, if one must drink it. Foul water at the outlet of a sewer will contain several kinds of Bacteria. Put a small drop of this water on a slide, add a cover, and examine with a high power of the microscope. There are three general types of Bacteria: the spherical ones are called *Coccus* forms; the straight, rodlike ones are

Bacillus forms; and the curved and spiral ones are *Spirillum* forms (Fig. 168*A*). All are likely to move vigorously and the *Spirillum* has a very characteristic snaky movement.

If you scrape the inside of your cheek with your finger nail, you are likely to get all three of these forms. They do no particular damage.

Some of the Bacteria which you can get by scraping your teeth are not only harmless but may even be beneficial. This is no reason for not brushing your teeth. Enough of the beneficial forms will be left after a couple of good brushings every day, and the brushings will lessen the number of toothaches and the number of teeth which have to be pulled (Fig. 168*B*).

Bacteria increase in numbers with startling rapidity. One divides and then there are two; each of these divides and then there are four. In some forms the divisions follow each other at intervals of ½ hour. It is interesting, and even terrifying, to find how many Bacteria there would be at the end of 2 days if division took place every ½ hour and all the Bacteria should live. Some one has estimated that at the end of 24 hours there would be 181,000,000,000,000 of them, about 1 pint. Starting the second day and keeping up this pace for 24 hours more, there would be 181,000,000,000,000 pints—enough to fill all the ocean basins 3,000,000 times, or to make 33,000 bodies as large as the earth.

Why do they not do it? Because they produce substances which ruin the material they need for food; they can get food only when it is very close; unfavorable conditions of light, temperature, and moisture kill millions of them; and they are eaten in immense numbers by microscopic animals. Various things keep down the numbers of both good and bad Bacteria.

Bacteria cause many diseases, among them tuberculosis, typhoid fever, pneumonia, influenza, lockjaw and others. Some of the most common and dangerous ones are shown in Fig. 168. Some Bacteria, like *Anthrax*, get into the blood vessels and multiply so rapidly that they interfere with the movement of blood in the capillaries. Figure 168*H* shows Bacteria in the capillaries of a mouse which died within less than 24 hours after infection. Bacteria also cause some of the most destructive diseases of plants, like the soft rots of Cabbage, Turnips, Carrots, Potatoes,

Celery, Tomatoes, Asparagus, Onions, and others. Leaf wilt of Tobacco is caused by Bacteria.

Some of the damage to plants can be avoided by refrigeration, by canning, pickling, and drying, or by keeping vegetables and fruits in the light, for many Bacteria cannot stand the light.

Souring of milk is caused by immense numbers of Bacteria. Keeping milk cool delays the souring because the Bacteria do not multiply so rapidly. Pasteurizing the milk, which is really a heating process, destroys the Bacteria and the milk will not sour until Bacteria get in.

Boiling the water kills those Bacteria which cause typhoid fever, and so removes most of the danger which comes from drinking impure water. In the Spanish War the proportion of men who died from typhoid fever was 383 times as great as in the World War. Typhoid vaccine, which made the men more or less immune to the typhoid bacillus, and care in regard to drinking water were the principal reasons for the great difference.

Some Bacteria are very useful to plants, like those which cause swellings on the roots of Clover and various other members of the Pea Family. They enable the plant to get from the soil some food which they could not get without the help of the Bacteria.

Phycomycetes.—The *Phyc-* is the same word we had in Cyano*phyc*eae, Chloro*phyc*eae, Phaeo*phyc*eae, and Rhodo*phyc*eae, where it meant Algae. The *-myc-* means Fungus. The whole word means the alga-like fungi, and it was suggested by the fact that some of these Fungi look more or less like *Vaucheria* and its neighbors in the Green Algae.

The Phycomycetes and the two remaining groups of the Fungi are characterized by the fact that the plant body is composed of filaments which may be separate or may be woven together in endless ways. The filaments are called the *mycelium.*

In the Phycomycetes a thread of the mycelium forms a continuous tube with no cross-walls, or only a few cross-walls in its later stages. The lower members of the group grow in the water and may be called the Water Molds. The higher members do not grow in the water, but are at their best in slightly moist surroundings. The Bread Mold is a good illustration of the latter class.

Saprolegnia.—The commonest of the Water Molds is *Saprolegnia.* It is a saprophyte and its favorite host is some dead insect. Get a glass of water, not such as you would drink but such as might have dead insects in it, and drop a few dead flies on the surface. There are likely to be zoospores or eggs of *Saprolegnia* in such water. If there are zoospores, they at once

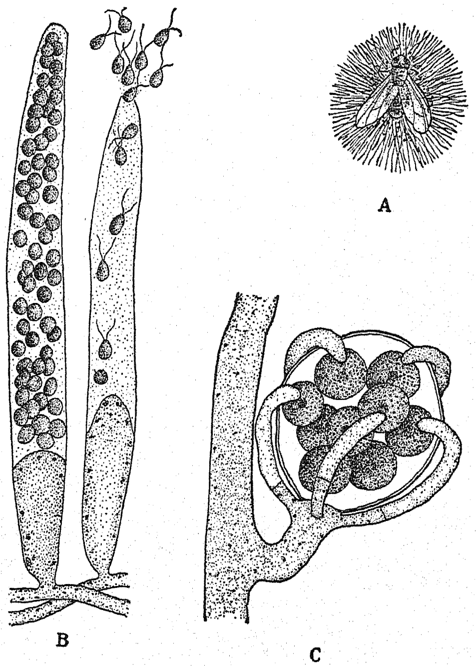


FIG. 169.—*Saprolegnia.* *A*, a fly with a three days' growth of *Saprolegnia*, natural size; *B*, two sporangia, the one on the left with nearly mature zoospores and the one on right with mature zoospores escaping; *C*, an oogonium with nine eggs; five antheridia are shown. *B*, *C*, *D*, × 300.

come to rest on the flies and within couple of days there will a be a halo of fungus threads, the mycelium, sticking out in all directions from the fly (Fig. 169). The ends of some of these threads become swollen, and zoospores are formed inside, so that the club-shaped end of the mycelial thread is a sporangium. A cross-wall separates the sporangium from the rest of the thread.

Water bad enough to have *Saprolegnia* zoospores in it is sure to have Bacteria also, and they attack both flies and the *Sapro-*

legnia. Besides, the fly itself is sure to have some Bacteria on it, and the culture is soon killed. But if the flies are washed under a stream of water every day, many of the Bacteria are washed off and the culture may last a week, producing sporangia with their zoospores all the time (Fig. 169).

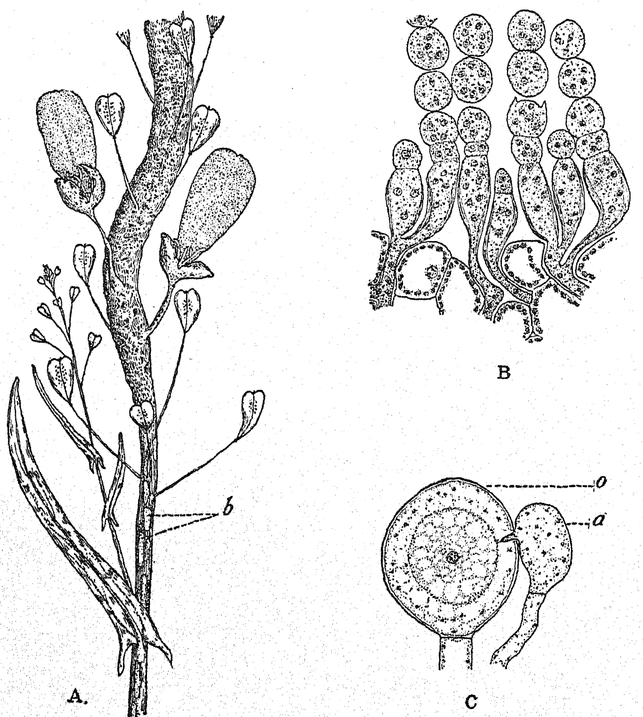


FIG. 170.—*Albugo candida, white Rust.* *A*, a piece of Shepherd's Purse infected with White Rust; white blisters are shown on the lower part of the stem, *b*; higher up, the stem is very much swollen and two of the pods are greatly enlarged. *B*, part of a section through one of the white blisters, showing rows of spores. *C*, an oogonium, *o*; and an antheridium, *a*. *A*, natural size; *B* and *C*, × 390.

After producing sporangia for a few days, the culture may produce oogonia and antheridia. Each oogonium contains several eggs, and, just below it, there will often be one or more antheridia containing sperms. A sperm enters an egg, its nucleus unites with the nucleus of the egg, which, thus fertilized, may rest for a time or may germinate at once, producing a mycelium which behaves like that coming from a zoospore (Fig. 169).

Achlya, a Water Mold looking very much like *Saprolegnia*, attacks living fishes and often does great damage.

Albugo candida (White Rust).—This fungus gets the name, White Rust, because its spore stages consist of white patches or blisters on the leaves and stems of plants, especially upon members of the Mustard family. The white blister is made up of crowded vertical rows of spores, which germinate immediately, each spore producing a few zoospores. The zoospores come to rest and produce mycelium which may develop more white blisters or may produce eggs and sperms (Fig. 170).

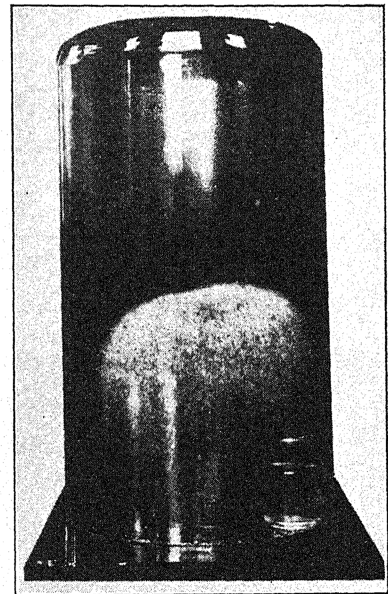


FIG. 171.—*Rhizopus*, Bread Mold. A slice of bread with mold four days old.

When eggs and sperms are produced, they cause great swellings of the infected parts. Stems, and especially pods, swell to several times their normal size. The end of a mycelial thread swells greatly and becomes an oogonium, with a cross-wall between it and the rest of the filament. One egg is formed inside each oogonium. Some neighboring filament enlarges slightly and becomes an antheridium containing many sperms (Fig. 170)

A sperm fertilizes an egg which then forms a thick wall and may rest for a long time. When it germinates, it produces zoospores which repeat the life history.

In the Water Molds both zoospores and sperms swim by means of cilia; in the White Rust zoospores have cilia and swim actively; but in all the rest of the fungi, from this point on to the end, there are no more swimming spores or gametes.

Rhizopus (Bread Mold).—*Rhiz-* means root and *-pus-* means foot. The name was given because the fungus clings to its host by filaments which look like roots. The cottony Bread Mold,

with little black dots scattered over it, is familiar to every one. Expose a slice of bread to the air for an hour, place it on a glass in a plate of water, and cover with a bell jar. The bread will soon be covered with a dense growth of Bread Mold (Fig. 171). While the slice of bread was exposed to the air, spores of the Mold fell on it and soon germinated, forming the dense mass of fungus. Every hour we breathe in some of these spores, but, fortunately, they do not grow as they do upon bread.

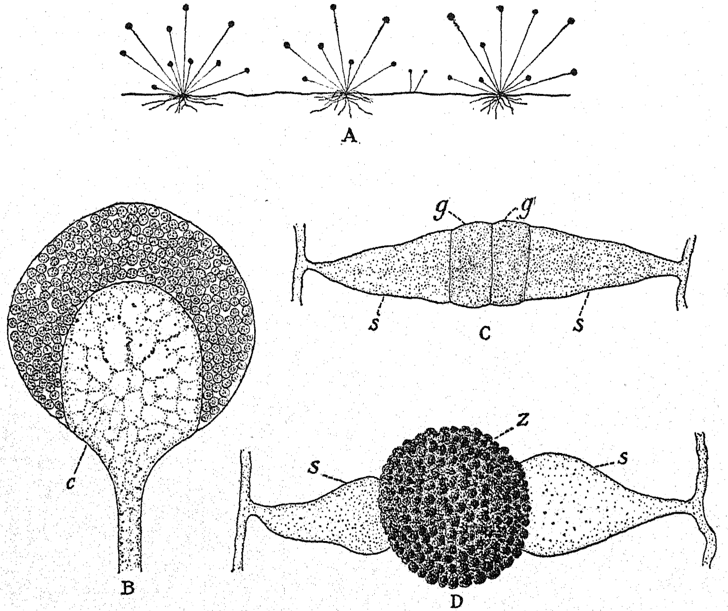


FIG. 172.—*Rhizopus*, Bread Mold. *A*, clusters of sporangia, connected by stolons and with rhizoids at the base of each cluster, × 3; *B*, section of a ripe sporangium with numerous spores; the swollen end of the stalk pushes up into the sporangium and is called a columella, *C*; *C*, two gametes, *g*, which unite to form a zygote, *z*, shown in *D*; the cells, *s*, are called suspensors. *B*, *C*, *D*, × 148.

The black dots, which one can see without a lens, are sporangia; and each sporangium is full of spores (Fig. 172*A*, *B*). The spores float in the air, and when they find a suitable host, germinate and produce the cottony mass of mycelium, which soon produces sporangia; and the process is repeated.

There is another mode of reproduction, but one scarcely ever finds it, because it appears only when two masses of mycelium,

differing from each each other in a certain way, come together. When two such masses do come together, however, gametes are formed which unite and form a zygote (Fig. 172*C*, *D*).

Various kinds of *Rhizopus* are very destructive to Sweet Potatoes, Irish Potatoes, Apples, and Pears. Since it gets a start in some place where the skin is broken, it may be called a *wound parasite*.

After the white Bread Mold has been growing for a few days, bluish green patches are likely to appear and become larger as the Bread Mold becomes weaker. This is another Mold. Later, dense black or bright orange patches may develop. This means that different kinds of spores were in the air and all fell on the bread while it was exposed. The white Bread Mold gets started quickly and restrains the others; but as the Bread Mold runs its course, the others appear and, finally, all the food-stuff in the bread is used up.

Ascomycetes (Sac Fungi).—*Asc-* means sac and *-myc-* means fungus; so Sac Fungi is simply a translation of the scientific name. They get their name from the fact that the sporangium which contains the spores is like a long sac. The mycelium consists of long rows of cells, each cell with one nucleus.

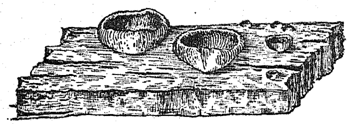
Peziza (Cup Fungus).—The red, orange red, or flesh-colored cups, from one-eighth of an inch to an inch in diameter, are the most familiar of the Sac Fungi (Fig. 173*A*). They are found on rotten logs or on soil which contains decaying organic matter; so they are saprophytic.

A piece of one of the cups, picked to pieces with needles, shows an immense number of sacs (*asci*), each containing eight spores (*ascospores*). Most of the Sac Fungi have eight spores in each sac. Many ends of filaments, somewhat swollen but not containing spores, are mixed with the sacs (Fig. 173*B*).

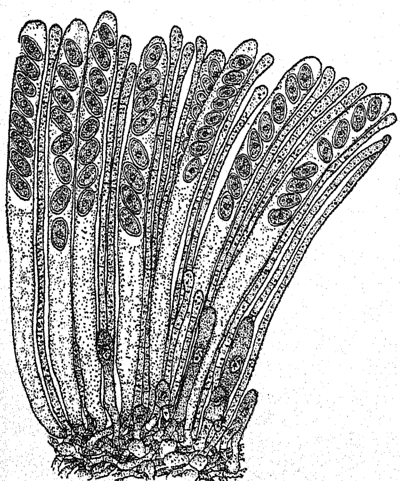
Green Molds.—Powdery green or bluish green patches are frequently seen on bread, cheese, old leather, and on various fruits, especially grapes. The powdery appearance is due to millions of very small spores. The commonest of these Molds is *Penicillium*.[1] Patches of *Penicillium* are likely to appear on the

[1] *Pencillium* means *brush* and the name was given because the spore-bearing part looks like a little brush. When pencils took the place of brushes in writing, the same name was applied to the pencil. We have

Bread Mold after a few days. It is easily recognized (Fig. 174). It also has a stage with asci and ascospores, but they are seldom seen. This Mold gives the bluish green color to Rocquefort cheese, and various species of it are used in making other cheeses. If an American full-cream cheese gets moldy in the pantry, it is generally thrown out; but we pay a high price for various moldy cheeses which have been



A



B

FIG. 173.—*Peziza*. *A*, habit sketch of several specimens growing on rotten wood, natural size. *B*, several mature asci, each with eight ascospores; some young asci near the base. The long slender threads are called paraphyses. × 230.

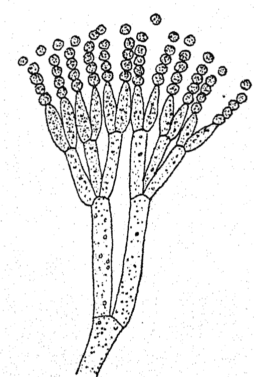


FIG. 174.—*Penicillium*. Piece of the spore bearing part of *Penicillium*, Green Mold, growing on bread. × 400.

infected intentionally. We prefer to have our grapes and apples and our bread without the mold.

Another bluish green mold, *Aspergillus*, looks much like *Penicillium* until you get it under the microscope (Fig. 175).

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simply dropped some of the letters—Pen(i)cil(lium). The word pen, has a similar history. A hundred years ago a feather was used to write with, the quill being sharpened and split, so that it looked somewhat like a pen. When pens began to be made of steel, they simply kept the feather name.

Morchella (Morel).—One of the larger members of the Sac Fungi is the *Morel,* which is rather widely known because it is one of the best of the edible fungi (Fig. 176).

The Powdery Mildews.—There are several of these very small fungi, all of them parasitic on leaves. The infected leaf looks as if it had been dusted with a powder puff. The powdery appearance is due to immense numbers of spores which break off and

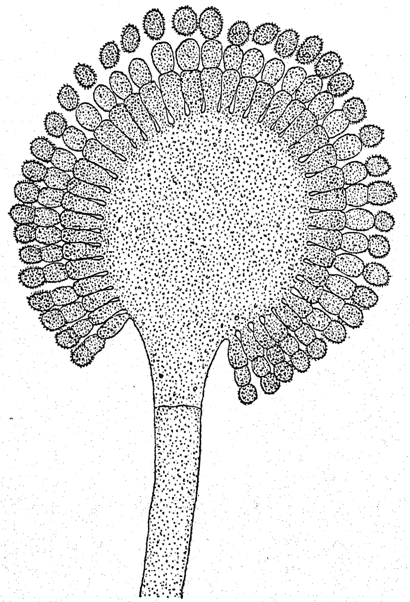


FIG. 175.—*Aspergillus.* Sectional view of a spore bearing hypha. × 400.

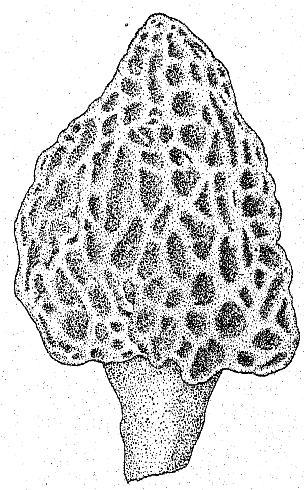


FIG. 176.—*Morchella,* the Morel. The edible portion, natural size.

spread the disease. Later, small black dots appear, much smaller than a small pinhead. These are hard cases (*perithecia*) containing the sacs. One of the commonest of the Powdery Mildews is found on Lilac leaves (Fig. 177). It is called *Microsphaera* (*small sphere*). It does not do much damage, because it usually appears after most of the work of the leaf is done. The powdery appearance is due to innumerable small spores which germinate at once and spread the disease. The tiny black cases enclosing the sacs can be seen without a lens; but, under a microscope, they are very complicated and beautiful. If one taps lightly on the

cover glass with a pencil or pen holder, the case cracks open and the sacs with their spores come out (Fig. 177).

Yeasts.—The yeasts are used in making bread and also in making beer and other drinks. They are saprophytes, living in juices of plants, which they change into sugar and alcohol. Yeast soon

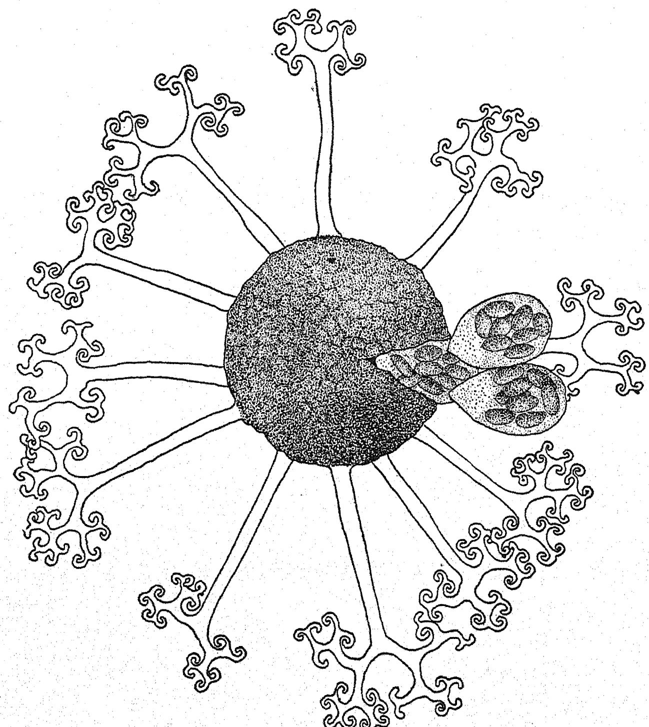


FIG. 177.—*Microsphaera*, Lilac Mildew. Single perithecium, crushed a little, so that three of the asci, each with its eight ascospores, are coming out. The appendages are gracefully branched at the tips. × 300.

changes sweet cider into hard, by changing some of the sugar into alcohol, a process which is called fermentation. Bacteria then come in and change the hard cider into vinegar.

Yeasts are unicellular. They have no zoospores and no gametes, but they multiply rapidly by budding. When some yeast is scraped off from a yeast cake into a water glass full of water and kept about 10° above room temperature, budding

soon begins (Fig. 178). When the food supply becomes scanty or conditions become hard in other ways, spores sometimes form inside the cell, usually just four spores. The cell then looks like the sac (ascus) of the Sac Fungi and so the Yeasts are put in this group. These spores are so light and dry that they float in the air everywhere. The dry vegetative cells also float in the air and can live for months. The pressed yeast cakes one gets at the grocery consist of the dry vegetative cells.

Imperfect Fungi.—There are thousands of fungi whose life histories are only imperfectly known, and so they have been called the Fungi Imperfecti, not because the fungi themselves are imperfect, but because only a part of their life history is known (Fig. 179). The stage which bears its spores exposed as in *Penicillium* does the damage. These spore stages look like spore stages in Ascomycetes, and, occasionally, some one finds the ascus stage with its ascospores. So, the whole group is put in the Ascomycetes because we think that when the missing stages are found, they will be the ascus stage with its ascospores.

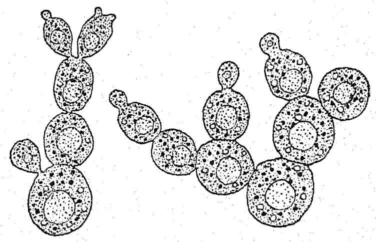


FIG. 178.—*Yeast, Saccharomyces.* Several cells showing budding. × 1330.

Lichens.—The Lichens are usually neglected in elementary courses, but they are very interesting, and in many places they are a conspicuous part of the plant life. They grow on sticks and stones, on the bark of trees, on rail fences, and other places.

A Lichen is made up of a fungus and an alga growing together. One could hardly say that the fungus is parasitic on the alga, because it does little or no damage; and, on the other hand, the two, associated in the form of a Lichen, can live where neither could live without the other. Such a relation is called *symbiosis*, a *living together*.

Some Lichens are leafy (*foliose*); some are shrubby (*fruticose*), and some stick tight to the surface upon which they grow, forming crust, so that they are called *crustose*. All three types may grow on the same twig (Fig. 180).

The Lichens are placed here in our study because in all but a couple out of a thousand species the fungus is a Sac Fungus. When spores are formed, there are cups much like those of Peziza

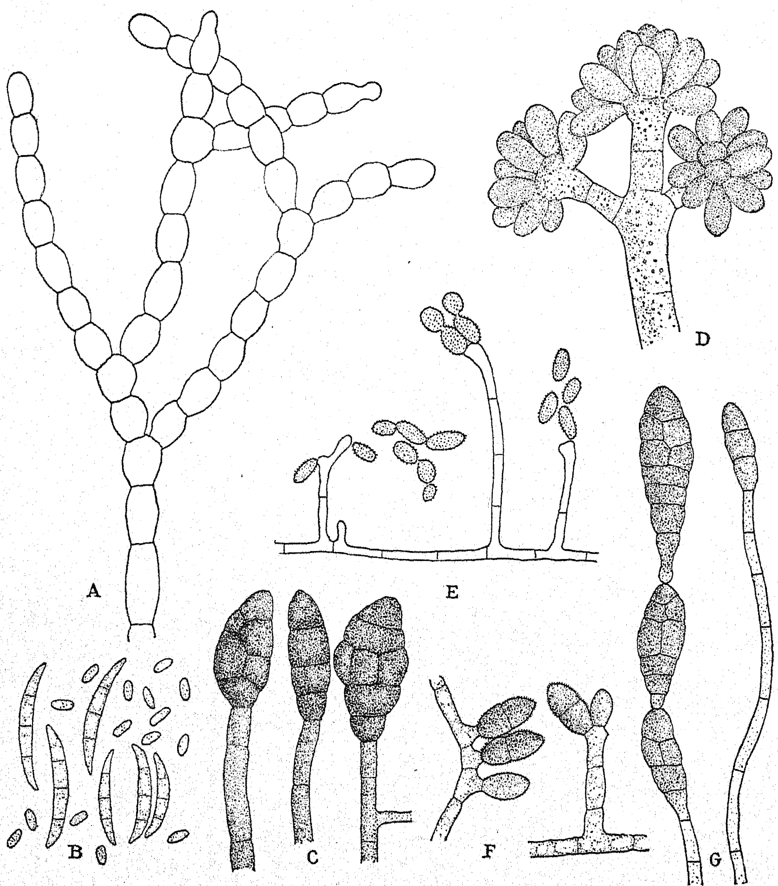


FIG. 179.—*Imperfect Fungi.* Several forms showing spores. *A*, *Monilia*, on Peaches; spores in chains: *B*, *Fusarium*, with large and small spores, on Tomato, the large spores with four cells; *C*, *Macrosporium*, with large multicellular spores on Tomato; *D*, *Botrytis*, with spores in clusters, on Lettuce; *E*, *Cladosporium*, with spiny spores; *F*, another kind of *Cladosporium*, on Tomato; *G*, *Alternaria*, with multicellular spores in chains, on Tomato. All × 435.

(Fig. 181*A*). A section through a Lichen at this stage shows how the fungus and alga are arranged to make up the whole structure (Fig. 181*B*).

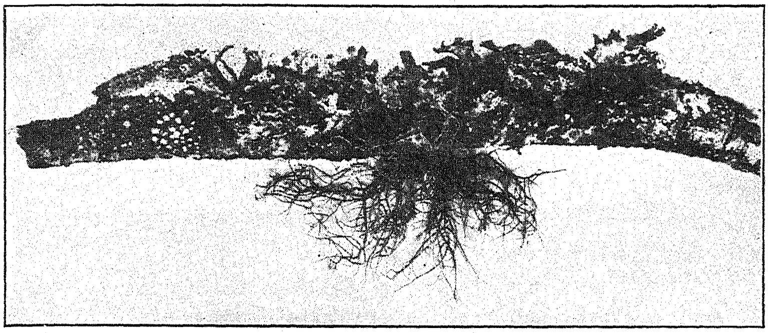


FIG. 180.—Lichens. Crustose, foliose, and fruticose Lichens growing on a stick at the Puget Sound Biological Station. Natural size.

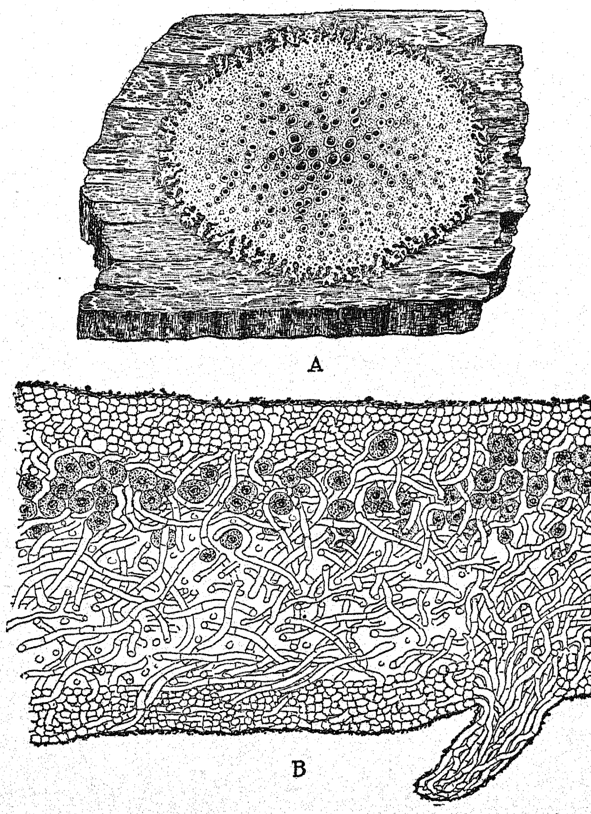


FIG. 181.—*Lichens.* *A*, *Physcia*, a very common lichen growing on bark. The numerous cups (apothecia) are large at the center and become smaller toward the edge. Natural size. *B*, section showing the unicellular alga (shaded) and the filamentous fungus. $\times$ 300.

Only members of the Blue Green Algae and Green Algae take part in the formation of Lichens, and they scarcely ever produce spores in this relation; but the fungus produces its sacs, each with its spores, usually just eight spores. When these spores germinate, they do not make a new Lichen but only the fungus element.

Many Lichens are scaly, however, each little scale consisting of some fungus threads and some alga cells. These scales (*soredia*) break off and grow into new Lichens.

Crustose Lichens, growing on rocks, change the surface so that the rocks crumble a little and, with decaying Lichens, make a shallow soil which supports Mosses, then larger plants, and, finally, shrubs and trees.

Basidiomycetes (Basidium Fungi).—Here belong the Smuts, Rusts, Mushrooms, Toadstools, Bracket Fungi, Puff Balls, Bird's Nest Fungi, and others which are so familiar that they have common names. Some of them are edible, some are poisonous, and many cause destructive diseases of various farm crops and trees. They get their name because their spores—usually in fours—are borne upon a club-shaped cell called the *basidium*. The mycelium has cross-walls, as in the Sac Fungi, but the spores are borne on the *outside* of the basidium, while in the Sac Fungi, the spores are borne *inside* the sac.

Smuts.—The Smut on Corn is a pest in almost every cornfield, where it forms large masses, sometimes as large as one's fist. The Corn plant is infected at any young, tender, growing part, especially young ears and tassels, where the mycelium develops great masses, causing such distortion that a grain (ovary) may swell to hundreds of times its natural size (Fig. 182). The swollen part might be called a plant tumor. It contains millions of black spores which look like Smut in the chimney and give the fungus its name. They germinate immediately and spread the disease; but they have a thick wall which can protect them through the winter. In the spring, they germinate, producing the basidium which bears four or more thin-walled spores. These germinate as soon as they fall upon a young tender part of the Corn plant (Fig. 183). Corn Smut causes immense damage, in extreme cases ruining half the crop. No one has yet found a way to prevent or control the disease.

Smuts of Wheat, Oats, and Barley also cause immense loss; but some progress has been made in preventing their spores from germinating and thus keeping down their ravages.

All the Smuts are parasites, because they grow upon living hosts.

Rusts.—The Rusts of Wheat and Oats cause millions of dollars of damage every year, but losses are becoming less as scientific studies develop methods of prevention. Students of plant diseases are having their greatest success in preventing or arresting diseases rather than in curing them.

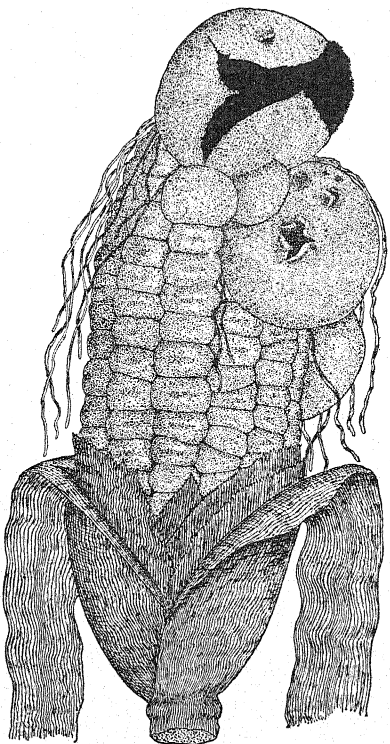


FIG. 182.—Smut (*Ustilago*). An ear of corn in which several grains have swollen immensely. Two of them have broken and show the black spores of the smut. Natural size.

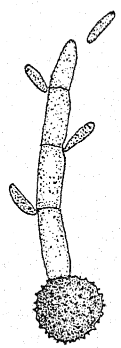


FIG. 183.—Smut (*Ustilago*). One of the spores which constitute the black mass of the Smut, germinating. Usually a filament of four cells, each bearing a spore (basidiospore) is produced when the black spore germinates. × 1420.

Some people will not take smallpox, even when exposed to it. They are *immune* to smallpox. Similarly, a plant, here and there, is immune to some disease which ruins its neighbors. Its seed should be saved and planted; for, by taking care, a seed plant will increase like the theoretical rate for Bacteria, and, in a few years,

there would be enough seed from the descendants of a single plant to supply the whole country.

The Wheat Rust has an extremely complicated life history, but it is well known and material is so easily secured that every one who studies fungi at all should know something about this destructive parasite. An interesting feature of the life history is that part of it is passed on the Wheat plant, and the rest of it on the Barberry bush. If all the Barberry bushes should be destroyed, the Wheat Rust would disappear; and in Denmark, where practically all the Barberry bushes have been destroyed, there is scarcely any loss on account of Wheat Rust. Since many millions of dollars are lost every year on account of Wheat Rust, extreme efforts have been made to destroy all the Barberry bushes. Students in the schools have gone through cities, towns, and the countryside, hunting and destroying the native Barberry bushes, for they are the only ones which do any damage, the beautiful little Japanese Barberry being perfectly harmless. It is so immune to the Wheat Rust that it cannot be infected artificially.

The native Barberry and the Japanese Barberry are easily distinguished (Fig. 184). The margins of the leaves in the dangerous native Barberry are spiny but perfectly smooth (entire) in the Japanese Barberry. The native Barberry has its flowers and red fruits in racemes, like a Currant; while in the Japanese Barberry the flowers and fruits occur singly or in pairs. In the native Barberry the branches have spines in groups of three or more; while in the Japanese Barberry they occur singly. The native Barberry is taller than the Japanese Barberry and is often called the Tall Barberry. So there should be no danger of digging up the beautiful harmless Japanese form which is popular as a small decorative shrub.

The stage in the life history which does nearly all the damage is known as the Red Rust. It appears as elongated red blisters on the leaves (Fig. 185*A*). When the Rust is bad the whole field may have a brick red tinge. Each blister is made up of an enormous number of spores (urediniospores), which are blown about the field and to neighboring fields, where they germinate immediately, and the diseases preads like a wild fire (Fig. 185*C*). The leaves manufacture the food which should go up to the

growing grains of Wheat, but the Rust cuts down the working surface of the leaf so that there is not enough food to develop a full head of Wheat. The result is a poor grade of Wheat and

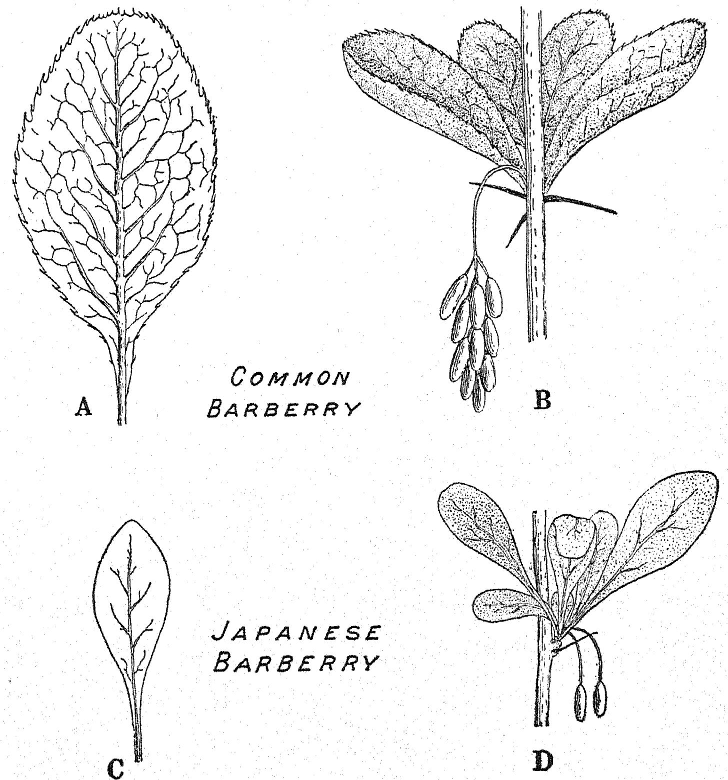
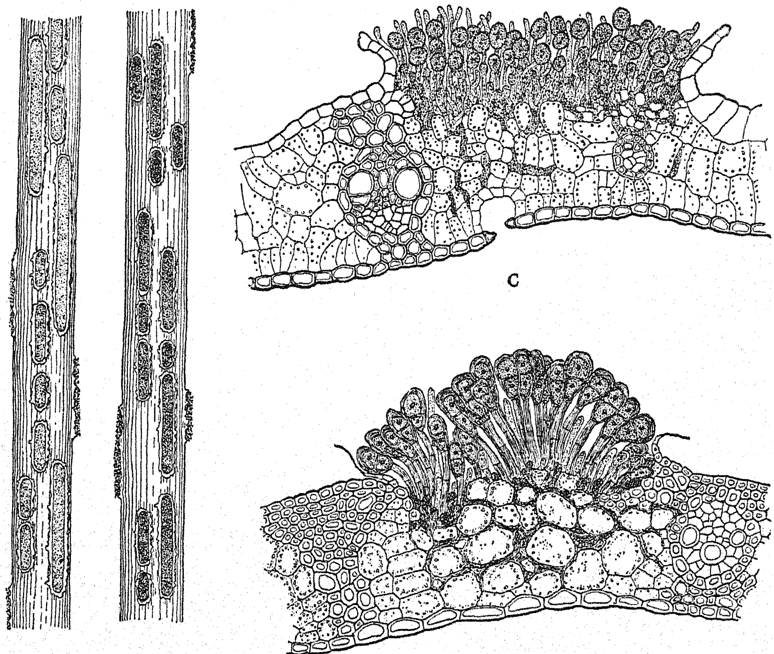


FIG. 184.—*Barberry.* How to recognize the Common Barberry and the Japanese Barberry. *A*, leaf of the Common Barberry with a spiny margin; *B*, cluster of fruit of the Common Barberry and the spines which are generally in three's; *C*, the much smaller leaf of the Japanese Barberry with smooth margin; *D*, fruit of Japanese Barberry, generally single or in two's, and generally only one spine. All about natural size.

fewer bushels to the acre. North of Texas the spores of the Red Rust are not likely to survive the winter in sufficient numbers to do much damage.

Later in the season the same mycelium which has been producing the Red Rust begins to produce black blisters on the leaves, but particularly on the lower part of the plant, so that

this stage is called the Black Stem Rust (Fig. 185*B*). This stage does not do much damage because it appears after nearly all the damage has been done. The black blisters are made of thousands of dark-colored spores, protected by very thick spore coats, so that they are able to survive the winter and start



A. B D

FIG. 185.—*Wheat Rust, Puccinia graminis.* *A*, streaks of Red Rust on sheathing base of leaf; *B*, streaks of Black Rust on stem; *C*, a section of a streak of Red Rust showing numerous summer spores (urediniospores); *D*, section of a streak of Black Rust showing numerous winter spores (teliospores); *A*, and *B*, twice natural size. *C* and *D* $\times$ 150.

the trouble the next spring. These spores, called teliospores because they are the last spores of the season, have two cells (Fig. 185*D*).

In the spring the teliospore germinates, producing a short four-celled filament, which is the basidium. Each cell of the basidium produces one spore called the *basidiospore* (Fig. 186). This spore cannot germinate on Wheat or on anything else, except the Common Barberry.

The basidiospore falls on the growing parts of the Barberry or other tender parts of the plant, especially the leaf, and quickly forms a mycelium beneath the surface. In a week or so, tiny

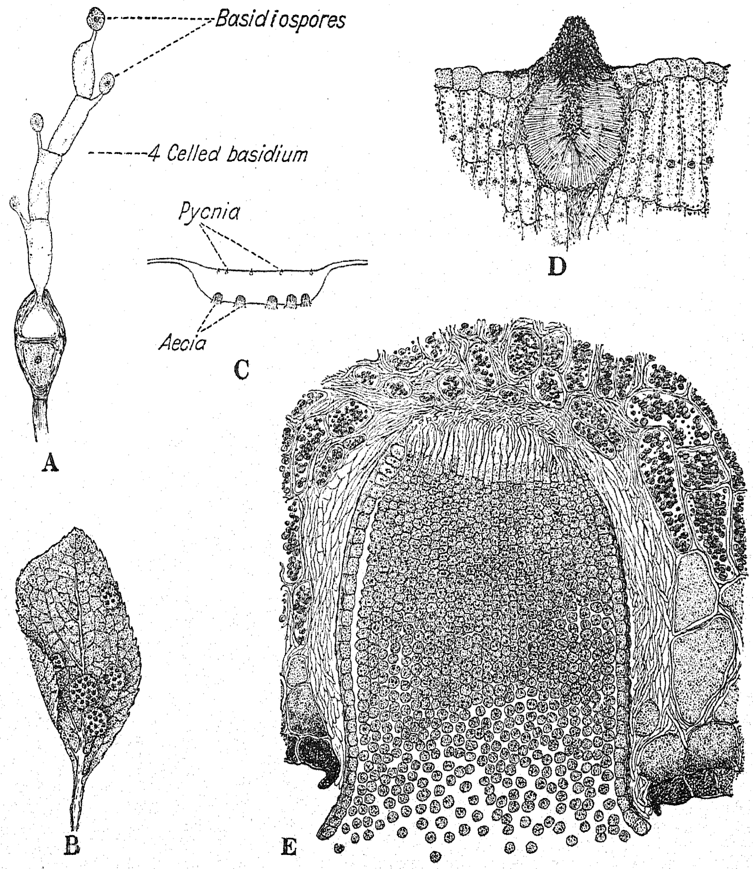


FIG. 186.—Wheat Rust, *Puccinia graminis*. *A*, germinating spore (teliospore) of Black Rust. Each cell of the 4 celled basidium has produced a basidiospore. × 300. *B*, basidiospores have germinated on Barberry leaf, producing swelling containing cluster cups (aecia). Natural size. *C*, cross section of Barberry leaf showing swelling caused by the fungus, × 6. *D*, a pycnium on the upper side of a leaf, × 150. *E*, a cluster cup (aecium) with countless spores (aeciospores), which germinate on wheat. × 150.

spots, barely visible to the naked eye, appear on the upper surface of the leaf and, soon after, much larger spots, often a quarter of an inch in diameter and with a yellow color, appear on the

lower surface. Each yellow spot is made up of several little cups, containing an immense number of spores arranged in rows.

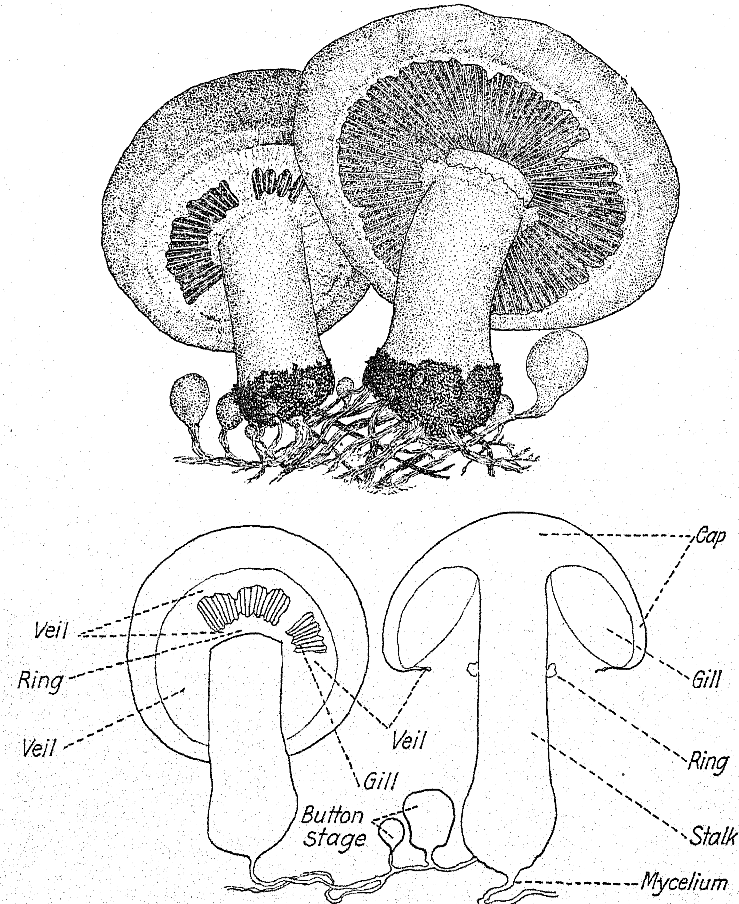
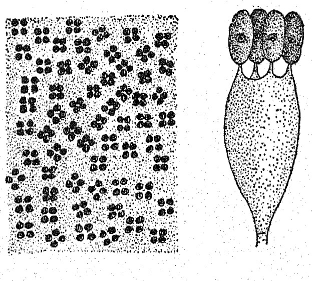


FIG. 187.—*The Field Agaric.* *A*, two nearly mature and some young ones in the "button" stage. In the one on the left, the veil has broken in two places, showing the gills beneath. In the one on the right, part of the veil is sticking to the border of the cap, and some of it forms a ring (annulus) around the stalk. The lower part of the stalk, with the dirt and mycelium (spawn) has been cut off in mushrooms sold at the grocery. Natural size. Below, a diagram with the names of the principal parts of a mushroom.

These spores (aeciospores) cannot germinate on the Barberry, but when they are blown to the Wheat, they germinate on the

leaves and cause the Red Rust, thus bringing the life cycle around to the point at which we started (Fig. 186).

Mushrooms and Toadstools.—A lot of fleshy fungi are included under the popular names, Mushrooms and Toadstools. It is not always easy to distinguish between them. When you eat them, if they taste good and digest well, they are Mushrooms; if you get sick or die, they are Toadstools. Cleopatra would have found out which were Mushrooms and which were Toadstools by feeding them to her slaves. Most of our own knowledge of edible and poisonous forms has



A B

FIG. 188.—A mushroom. *A*, surface view of a gill showing the basidiospores in fours; *B*, a single basidium with four spores.

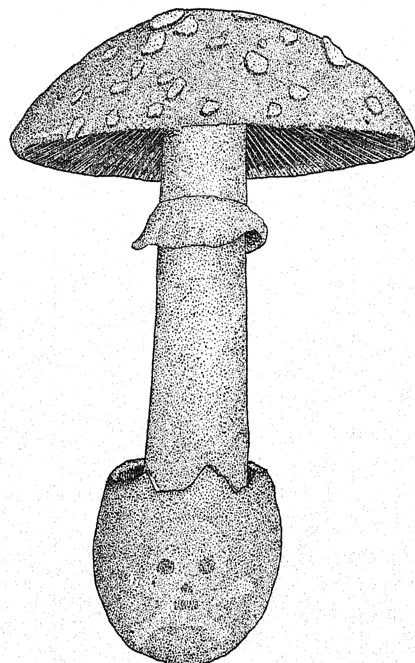


FIG. 189.—*Amanita phalloides.* A deadly poisonous Toadstool, showing a prominent ring and the "death cup." Natural size.

accumulated from experience. It is best to become thoroughly familiar with a few forms, so that you know them as a forest ranger knows an Oak, a Beech, a Maple, or a Pine, Fir, or Spruce, and let the rest alone. The Shaggy Mane Mushroom, the Field Agaric, and a few others are abundant and are easily recognized. The Mushroom at the grocery store is always the Field Agaric (*Agaricus campestris*), and this is always the one served with your steak.

The structure of the whole group of Mushrooms and Toadstools is well illustrated by the Field Agaric (Fig. 187). At the top

there is a cap with numerous thin plates (gills) extending from the stalk to the edge. In early stages of growth the gills are covered by a veil; but when the veil breaks, part of it is often left as a ring around the stalk. The bottom of the stalk is

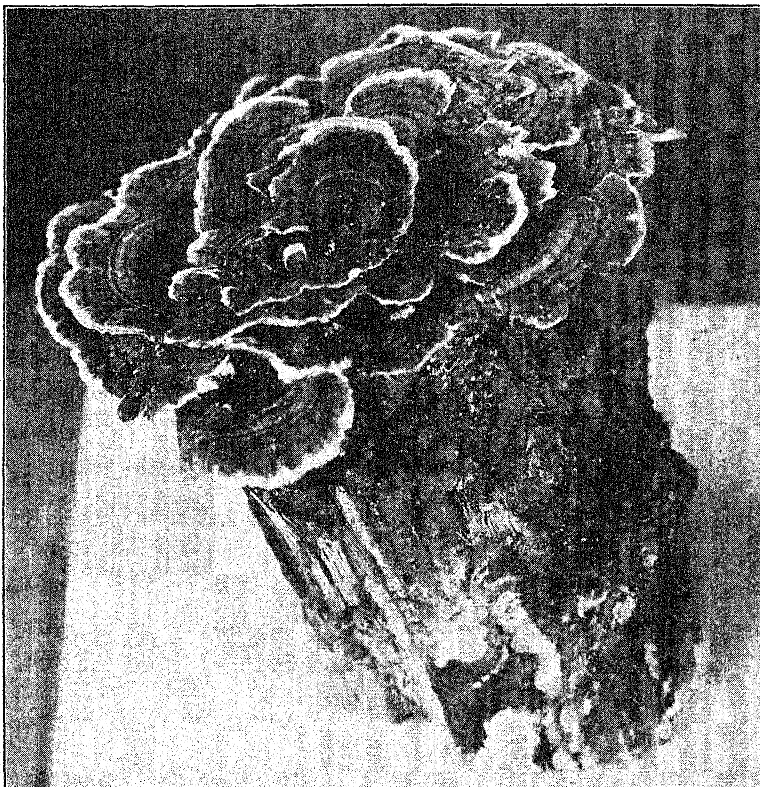


FIG. 190.—*Polyporus versicolor*. A Bracket Fungus growing on a piece of wood. About natural size. (*From a photograph furnished by Miss Lucile Capt.*)

somewhat swollen and the whole structure is the fruiting part of the fungus, coming from a mass of mycelium which is the vegetative body of the plant.

The gills are thin plates bearing thousands of spores. If one lays a gill on a slide and examines it with a low power of the microscope, he will see the small spores arranged in fours, cover-

ing the whole surface of the gill (Fig. 188*A*). A few forms (and one of them is the Field Agaric) have spores in twos.

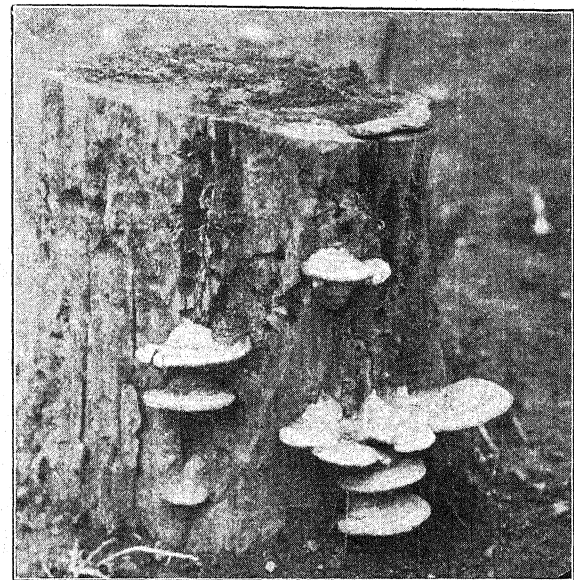


FIG. 191.—*Fomes applanatus.* Bracket Fungus on a stump. (*From a photograph furnished by the Jamison Studio.*)

The four spores are borne on a basidium, which consists of a single cell (Fig. 188*B*). When the spore germinates, it forms a

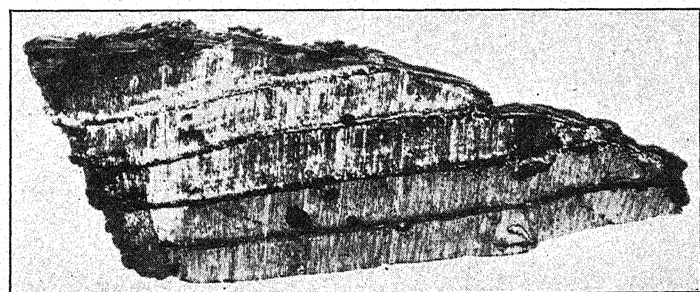


FIG. 192.—*Fomes applanatus.* Section of Bracket Fungus showing six layers of pores, representing six years' growth. About two-thirds natural size.

mycelial thread and, finally, a fruiting body, with its cap, gills, and other structures, thus making the life history complete.

Some of the poisonous forms have a cup at the base of the stalk. The cup has been called the death cup, because so many forms which have it are so fatally poisonous. More than a score of persons die every year because they think they can distinguish the safe forms with cups from the dangerous ones (Fig. 189).

The Bracket Fungi.—Many of the Bracket Fungi are very familiar as woody shelves sticking out from the sides of trees or logs. Some of them are large, a foot or more across; and some of them are small and beautiful (Figs. 190, 191).

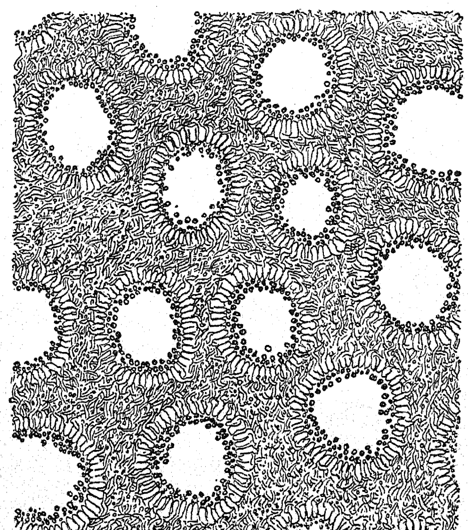


FIG. 193.—*Polyporus.* A transverse section across the pores, showing the lining of basidia and basidiospores. × 85.

Most of the Bracket Fungi have thousands of small pores on the underside; one genus is called *Polyporus* (many pores) and others, which do not have that name, have just as many pores.

The large woody Bracket Fungi live several years and form a new layer of pores each year (Fig. 192).

A cross-section through the pore region shows that each pore is lined with basidia, each of which produces four spores (Fig. 193).

The Puff Balls.—The Puff Balls are also familiar fungi, most of them ranging from the size of a Hickory nut up to immense forms larger than one's head (Fig. 194). Many are about as

large as a Peach. They are not poisonous and are very palatable, until they begin to get dark colored on account of the ripening spores.

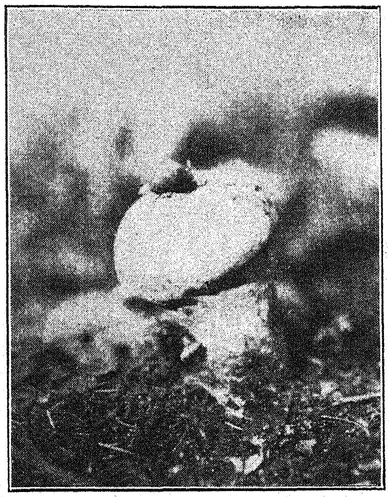
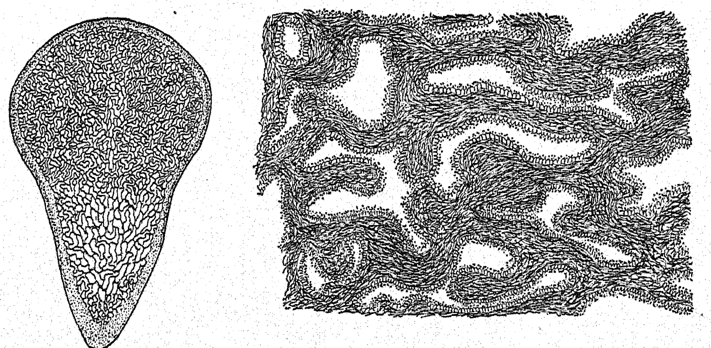


FIG. 194.—*Lycoperdon pyriforme*, a Puff Ball, natural size. (*From a photograph by Sedgwick.*)



A B

FIG. 195.—*Lycoperdon pyriforme*, a Puff Ball. *A*, longitudinal section, showing the immense number of cavities. Twice natural size. *B*, a section showing a few of the cavities, lined with basidia and spores. × 150.

They get their name because, when they are ripe, the spores puff out like a little cloud of smoke. The spores are borne in irregular cavities inside the Puff Ball (Fig. 195).

The Bird's Nest Fungi.—These beautiful little fungi may escape notice, because they are so small; but if you look in the right kind of places, you are likely to find them. In parks, where there is straw manure around shrubs and bushes, they are often abundant,

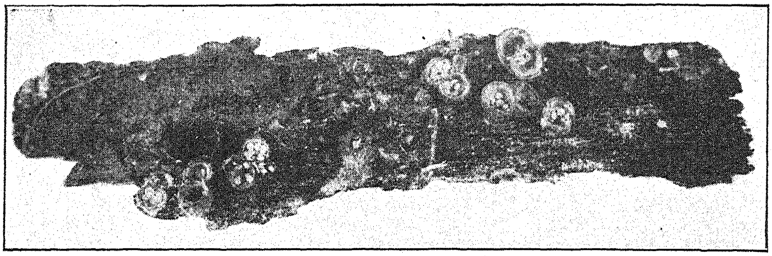


FIG. 196.—*Crucibulum vulgare*, a Bird's Nest Fungus. About two-thirds natural size.

growing in crowded groups. Around chicken coops you may find them on the ground or on twigs or boards. They are sometimes found on dead branches lying on the ground (Fig. 196).

The Bird's Nest Fungus is related to the Puff Ball. There is a tough outer wall—the nest—and an inner soft part which breaks up into several pieces—the eggs—which have a hard "shell." The basidia with their spores are inside the egg.

CHAPTER XI

BRYOPHYTES

Bry- means moss and *phyt-* means plant; so the Bryophytes are the Moss Plants.

They are distinguished from the Thallophytes by the fact that they have *archegonia.* The oogonium of the Thallophytes is a unicellular structure, containing one or more eggs; while the

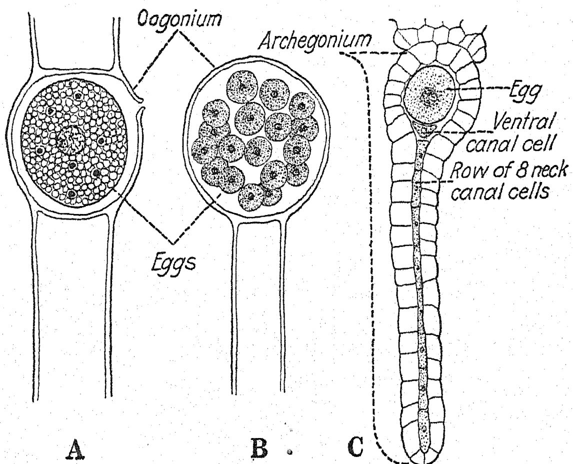


FIG. 197.—*A*, oogonium of *Oedogonium* containing one egg. *B*, oogonium of *Saprolegnia* containing several eggs. In both *A* and *B*, and in all other Thallophytes, the oogonium consists of only one cell. *C*, the archegonium of *Marchantia*, consisting of an enlarged part, the venter containing the egg and the ventral canal cell; and a narrower part, the neck, containing the neck canal cells.

archegonium is multicellular and contains one egg and some sterile cells (Fig. 197). Besides, all the Bryophytes have *alternation of generations,* a feature which will be emphasized from this point to the end of our studies. Many Thallophytes have alternation of generations, but we have not called attention to it, except in the case of the big Kelps (see page 184).

A few grow in the water, a few grow on dry rocks, more grow on the bark of trees, but most of them grow in damp places. The fact that they grow in damp places favors the theory that their remote ancestors were algae which migrated to the land and became modified to fit them for land conditions.

There are two large divisions of the Bryophytes, the Liverworts and the Mosses.

LIVERWORTS (HEPATICAE)

A few of the Liverworts grow in the water or float on the surface, but most of them lie flat on the ground or on damp logs or bark, clinging to the surface by numerous white cottony hairs called *rhizoids*. Some of them are flat and branching, from the size of one's little finger nail up to large plants two or three inches in length; but by far the greater number of them are leafy. The leaves, in the leafy forms, have no midrib.

Riccia.—A species of *Riccia*, called *Riccia natans* because it floats, is rather common in the spring, when it can be found floating on the surface of shallow ponds and ditches (Fig. 198*A*). The largest specimens may be as large as one's finger nail but most of them are smaller. It is a thick puffy little plant while it is in fruit, but gets harder and thinner after the fruiting season is over. It keeps growing in front and dying off behind during the summer and autumn, but gets hard as winter approaches and remains in a resting state until warmer weather starts it to growing the next spring.

The cells are loosely arranged and, in the upper part, there are large air cavities. On the lower side there are numerous scales. As long as the plant is floating there are few, if any, rhizoids; but when it comes to rest on wet ground, rhizoids appear in great numbers.

A section through one of the smaller plants will show antheridia in a row along the groove (Fig. 198*B*). They remind one of the gametangia of *Ectocarpus* (Fig. 157). In *Ectocarpus* all of the cells of the gametangium produce gametes; but in *Riccia* there is an outer layer of cells which merely protects the gamete-producing cells within. The gametes are called *sperms* and the gametangium producing them is called an *antheridium*.

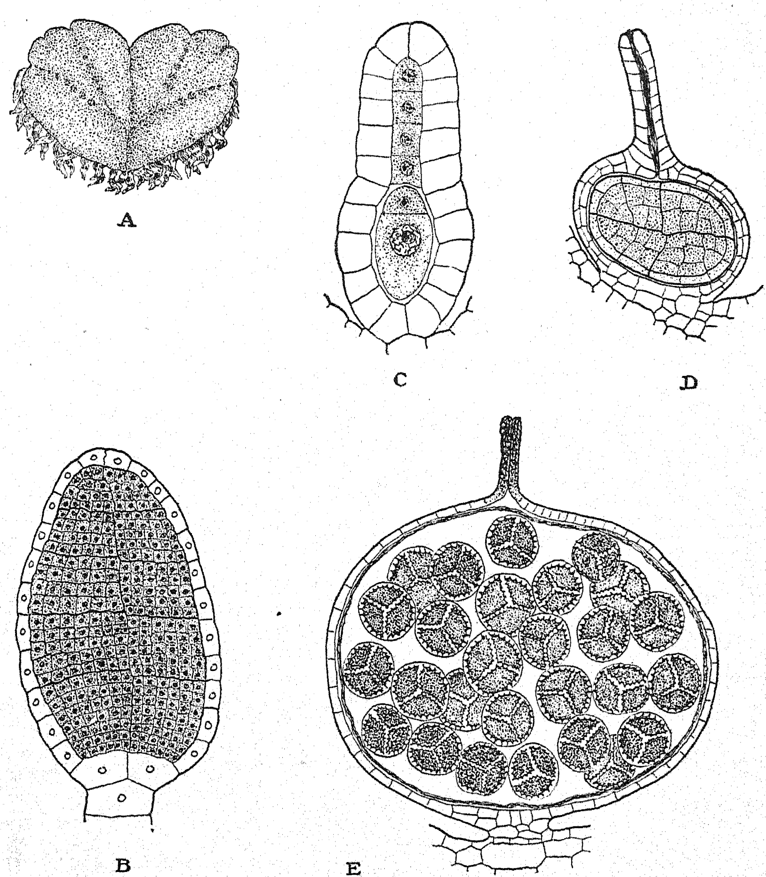


FIG. 198.—*Riccia natans*. *A*, habit sketch showing numerous scales and four rows of sporophytes. Twice natural size. *B*, a nearly mature antheridium, whose inner cells (shaded) will produce sperms; the outer layer of cells (not shaded) are merely protective. × 345. *C*, a nearly mature archegonium. The lower shaded cell with the large nucleus is the egg; just above it is the ventral canal cell; and above that are four neck canal cells. × 720. *D*, a young sporophyte developing from the fertilized egg, and enclosed in the much swollen archegonium. The outer layer of cells (lightly shaded) are sterile; the inner more deeply shaded cells will produce spores. × 200. *E*, nearly mature sporophyte, enclosed by the greatly swollen venter of the archegonium. The neck has become almost black. The outer layer of cells of the sporophyte have broken down and are represented by a line. Four spores (only three can be seen at a time) have been formed from each mother cell. × 100.

After producing antheridia for a while, the same plant begins to produce *archegonia*. This organ is so characteristic of Bryophytes, Pteridophytes, and Gymnosperms that these groups are sometimes called the *Archegoniates*. The archegonium of *Riccia* contains one egg, one *ventral canal cell*, and four *neck canal cells* (Fig. 198*C*). Surrounding these six cells is a layer of cells which protects the egg and the other cells within.

Far back in the ancestry of *Riccia* the ventral canal cell and the neck canal cells may have been gametes, but they no longer behave like gametes; they merely swell and burst open the neck of the archegonium when the time for fertilization arrives, oozing out as a syrupy fluid in which the sperms swim down to the egg. One sperm unites with the egg, thus fertilizing it and stimulating it to further development.

The fertilized egg does not develop into another plant like the *Riccia* plant with which we started. It divides many times and produces a spherical mass of hundreds of cells. The outer layer of these cells protects those inside, which round off and are called *spore mother cells*, because each one of them produces four spores (Fig. 198*D*, *E*). When one of these spores germinates, it grows into the floating *Riccia* plant with which we started.

So, there is a spore-producing generation, the sporophyte, and a gamete-producing generation, the gametophyte, which alternate with each other. The fertilized egg is the beginning—the first cell—of the sporophyte, and spore is the beginning—the first cell—of the gametophyte.

It is worth while to study the life history of *Riccia;* for, from this point on to the highest members of the plant kingdom, there are antheridia and archegonia, and a sperm fertilizes an egg which develops into a new plant.[1] There are differences in details, but the general course of the life history is the same.

Marchantia.—*Marchantia* is a much more complex Liverwort than *Riccia*. Since it is much larger, it is less likely to be overlooked. It is found in wet open woodlands, on damp banks of Cat Tail swamps, and, in almost any place where there has been a fire, *Marchantia* is likely to be found for several years (Fig. 199).

[1] In the highest flowering plants the archegonium is so reduced that only the egg remains.

Many plants reach two inches in length and some are even longer. The surface of the plant is laid off in tiny diamond-shaped areas with a little pore in the center of each one. These are very conspicuous under a pocket lens, but can be seen with the naked eye. A section shows that the upper and lower parts of the plant are different (Fig. 200).

The pore opens over a chamber from the bottom of which arise many branching filaments containing chloroplasts. Most of the

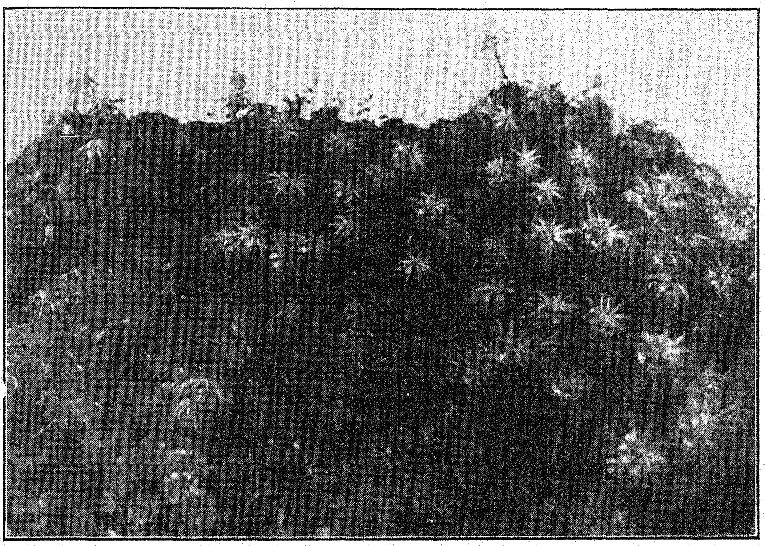


FIG. 199.—*Marchantia polymorpha.* About one-half natural size.

chlorophyll work is done here, the cells below being almost colorless. On the under surface are coarse scales and numerous rhizoids which hold the plant to the surface and absorb moisture.

Early in the development of the *Marchantia* plant, little cups (cupules) about one-eighth of an inch in diameter appear on the upper surface. Inside each cup are numerous thin multicellular bodies on delicate stalks from which they easily break off. These little buds, which are usually called *gemmae,* while large enough to be seen easily without a lens, are so small that a few drops of water will float them out from their cups. They grow immediately into new plants and rapidly increase the number of individuals; so that they serve the same purpose as the zoospore stage

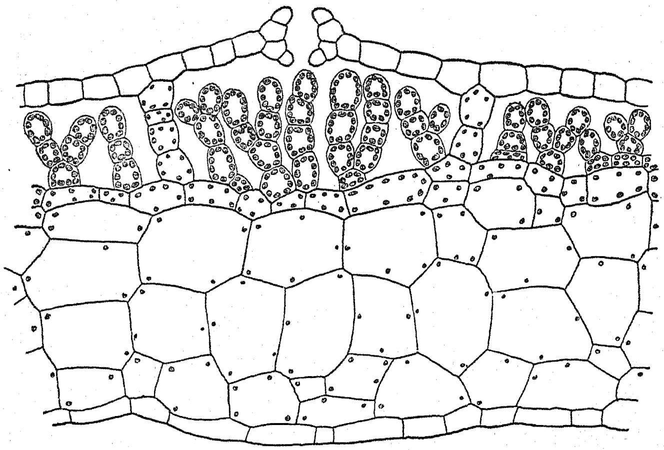


FIG. 200.—*Marchantia polymorpha.* Section through the vegetative body of the plant showing an air pore opening into a chamber containing filaments with chloroplasts. There are some chloroplasts in the cells below, but not so many. × 300.

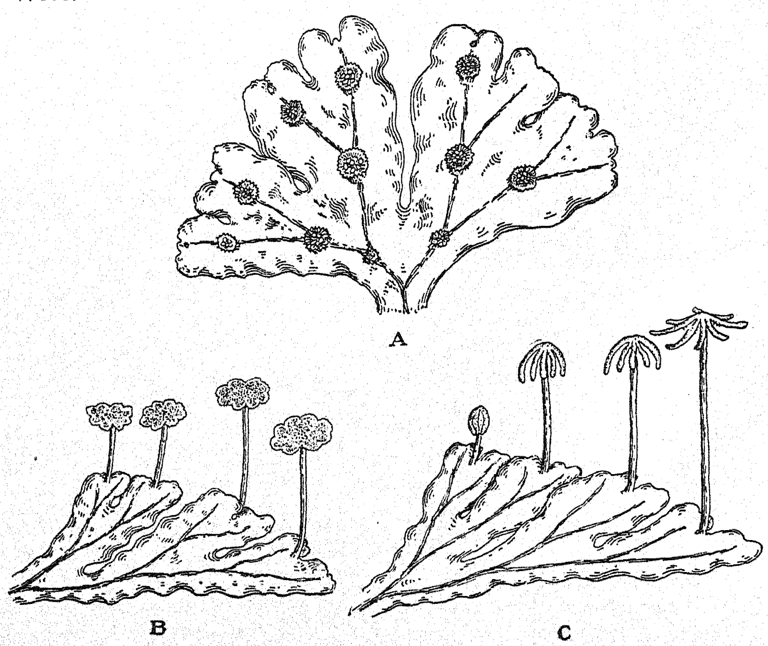


FIG. 201.—*Marchantia polymorpha.* *A*, plant with cupules containing gemmae; *B*, plant with the stalked, umbrella-like structure which contains antheridia; *C*, stalked structure which bears archegonia. All natural size.

in Algae, the spore stage in Bread Mold, the spore of the Red Rust of Wheat, and hosts of others (Fig. 201*A*).

The antheridia and archegonia are borne in special structures which are stalked up high above the surface of the prostrate plant (Fig. 201*B*, *C*). They are borne upon different plants, but the little cups, with their gemmae, are borne upon both antheridial and archegonial plants. It is interesting to note that gemmae from the little cup of an antheridial plant always produce more antheridial plants, and those from the archegonial plant always produce more archegonial plants.

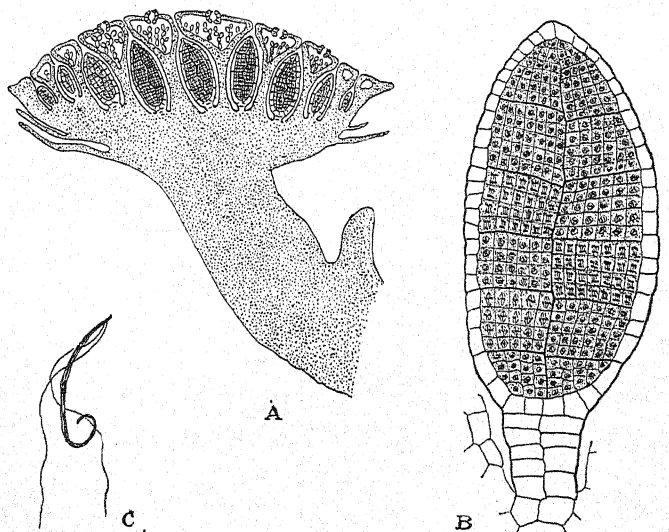


FIG. 202.—*Marchantia polymorpha*. *A*, section through the antheridial structure showing nine of the numerous antheridia, × 40; *B*, a nearly mature antheridium, × 200; *C*, a single sperm with two cilia, × 1,200.

A longitudinal section of the young antheridial structure shows antheridia of various ages, with the youngest stages at the outer edge. The antheridium is very much like that of Riccia, with a protective layer of cells at the outside and all the cells within producing sperms (Fig. 202*A*, *B*, *C*).

A similar longitudinal section of the archegonial structure shows several archegonia hanging down (Fig. 203*A*, *B*, *C*). As in Riccia, there is one egg and one ventral canal cell; but in Marchantia there are usually eight neck canal cells. The whole row

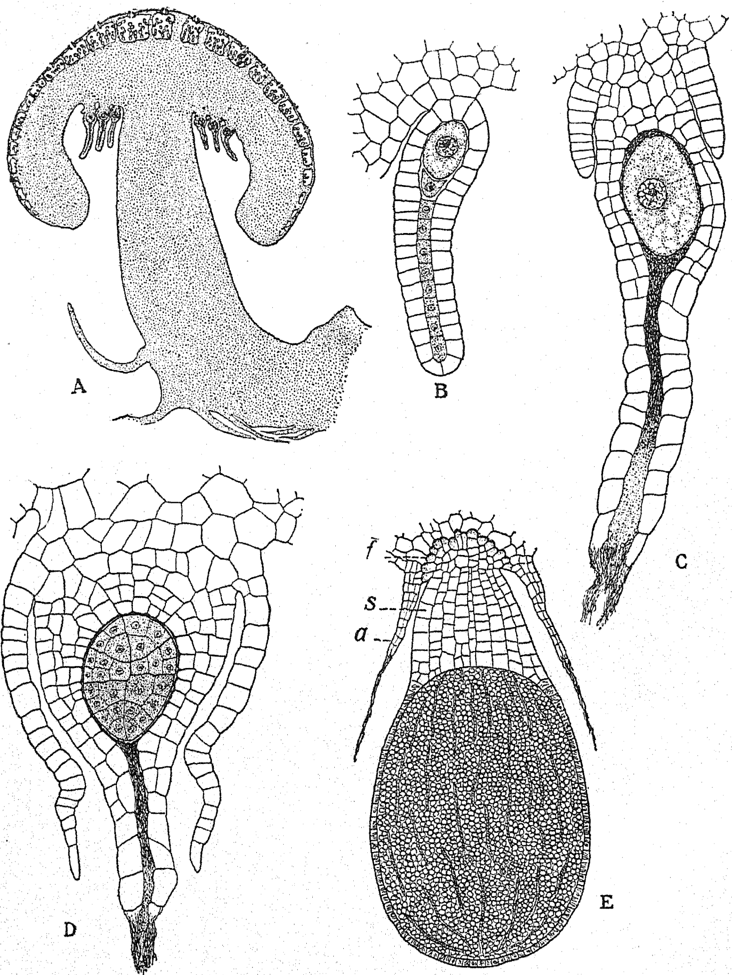


FIG. 203.—*Marchantia polymorpha.* *A*, section through the stalked archegonial structure, showing the archegonia hanging down, × 30. *B*, a single archegonium, shortly before fertilization of the egg, showing the egg, ventral canal cell, and eight neck canal cells, × 300. *C*, the egg after fertilization, × 300. *D*, the egg has divided, forming an embryo; the lower half of the embryo, which will finally produce spores, is more deeply shaded than the other half which will produce the foot and stalk, × 300. *E*, nearly mature embryo (sporophyte) showing the foot (*f*), stalk (*s*) remains of the ruptured archegonium (*a*), and the spore-bearing part, × 45.

of canal cells becomes a watery mucilaginous mass, which bursts open the neck of the archegonium and allows the sperms to swim down to the egg. One of the sperms fertilizes the egg, which immediately begins to divide.

In the development of plants, as we proceed from lower to higher forms, a smaller and smaller proportion of the sporophyte produces spores; and more and more of it is devoted to protection, to absorbing and manufacturing food, and to transporting food to places where it is used. There is an increasing division of labor as we go from the lower to the higher plants.

In *Riccia* all of the sporophyte, except an outer layer of protective cells, produces spores. In *Marchantia* much less than half of the sporophyte produces spores (Fig. 203). Besides a *foot* and a *stalk* there is an outer protective layer of cells, and many of the cells inside do not produce spores but develop into long threads with spiral bands, which help to scatter the spores when they get ripe (Fig. 203*E*).

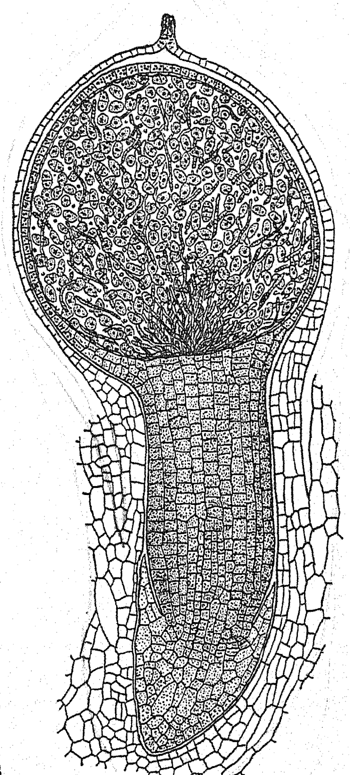


FIG. 204.—*Pellia epiphylla.* Sporophyte, nearly mature but still enclosed within the archegonium. At the top, is the neck of the archegonium shaded almost black, and below is the much stretched lower part of the archegonium. The sporophyte (shaded) consists of a spore-bearing part with sterile threads (elaters) among the spores; and, below this, a stalk and an anchor shaped foot. × 40.

When the spore germinates, it grows into the *Marchantia* plant with which we started. As in *Riccia*, the small sporophyte alternates with the much larger gametophyte. The sporophyte in all the Liverworts and Mosses is parasitic upon the gametophyte.

Pellia.—*Pellia* is about as large as *Riccia*, but is much thinner and has a darker color. Shaded ravines, clay banks, and shales along rivers are promising places

when you are hunting this little Liverwort. It has antheridia and archegonia on the same plant, but the antheridia develop for a while before archegonia begin to appear. After fertilization the egg develops into an erect sporophyte in which even a smaller proportion produces spores than in Marchantia (Fig. 204).

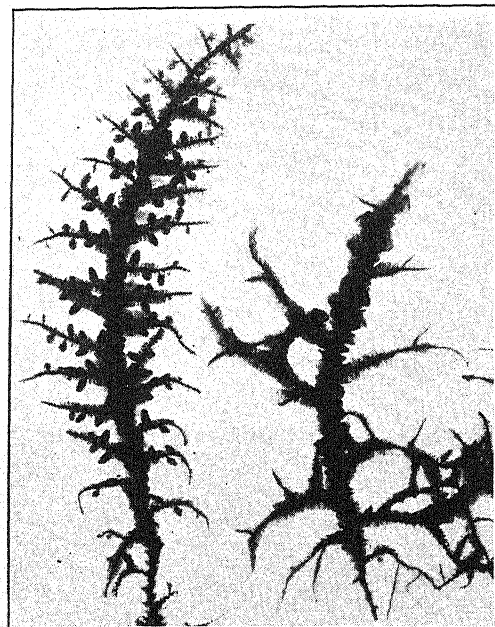


FIG. 205.—*Porella, a Leafy Liverwort.* On the left, an antheridial piece of the plant with many short antheridial branches; on the right, an archegonial piece showing several large leaves which cover the archegonia. A photograph, natural size.

Porella.—The Liverworts which we have studied up to this point are flat and more or less ribbon-like, but most Liverworts are leafy. Many of them are small and delicate and few are as large as Marchantia; but they often grow in mats, so that they might be mistaken for Mosses (Fig. 205).

Porella is a good example of the leafy type because it is rather large, easy to recognize in the field, and easy to keep alive. A favorite place for it is on logs and on the lower buttressing part of tree trunks. It may grow in large mats, looking like a Moss,

until you have learned the difference between a Liverwort and a Moss.

The leaves are of two kinds: the upper leaves, called dorsal leaves, and smaller leaves on the underside, which are called ventral leaves. There are twice as many of the dorsal leaves as ventral, and the lower part of each dorsal leaf is turned up so that a careless observer might mistake it for one of the ventral leaves (Fig. 206*A*).

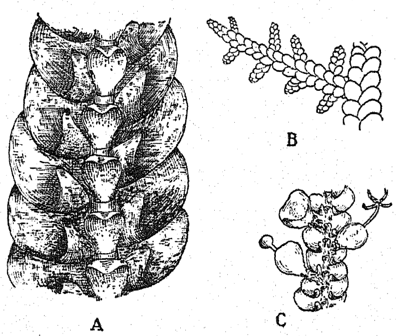


Fig. 206.

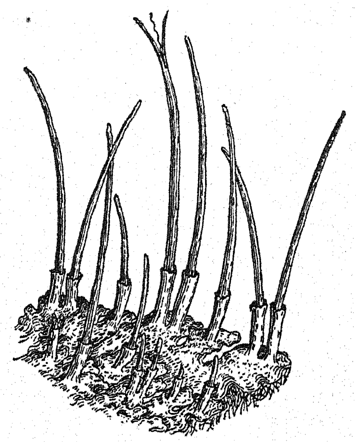


Fig. 207.

Fig. 206.—*Porella.* *A*, small piece viewed from the under side, showing the small leaves along the middle, and the larger leaves with the lower part, next the stem, curiously turned up, × 10. *B*, eight antheridial branches along the side of a small branch from the main axis, × 2. *C*, piece of the main axis with three of the large leaves which cover the archegonia. In the lower on the left, the knob-like sporophyte is projecting a little beyond the big leaf; in the one just above, the sporophyte is still covered by the leaf; in the one on the right the sporophyte has split into four parts and shed its spores. × 2.

Fig. 207.—*Anthoceros.* A group of plants with long, horn-like sporophytes, × 2.

The antheridia are borne on special branches with very small leaves, and the archegonia are borne in a cluster at the top of a very short side branch and are protected by a leaf much larger than the foliage leaves (Fig. 206*B* and *C*).

A sperm fertilizes an egg which develops into a sporophyte, with a foot, a stalk, and a spore-bearing capsule at the top. When the spores are ripe, the stalk lengthens rapidly, thus lifting the spore-bearing part into the air, with a better chance to

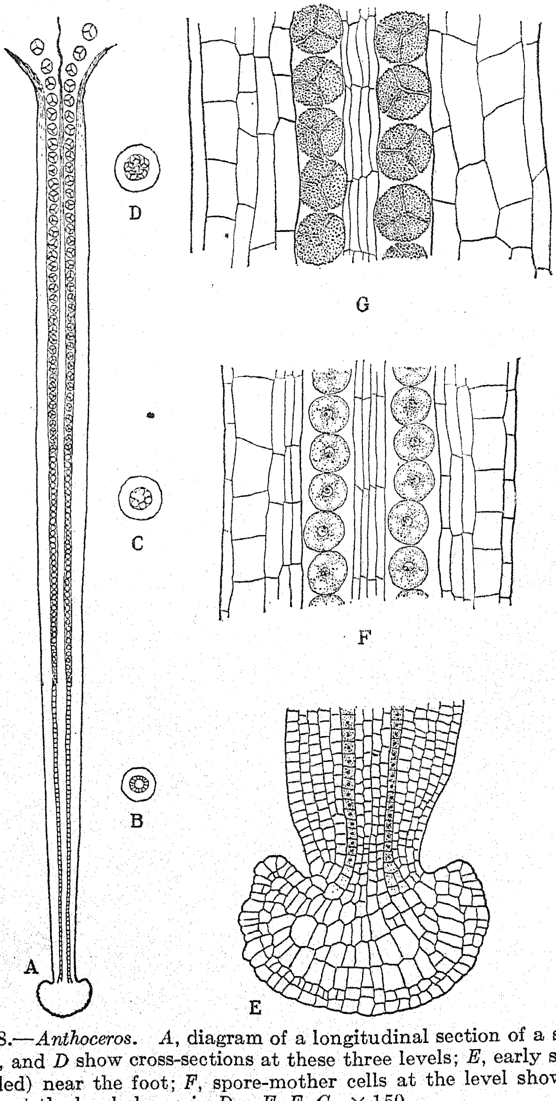


FIG. 208.—*Anthoceros.* *A*, diagram of a longitudinal section of a sporophyte, × 5; *B*, *C*, and *D* show cross-sections at these three levels; *E*, early sporogenous cells (shaded) near the foot; *F*, spore-mother cells at the level shown in *C*; *G*, ripe spores at the level shown in *D*. *E*, *F*, *G*, × 150.

scatter its spores. The capsule splits into four parts as the spores are thrown out (Fig. 206*C*). When a spore germinates, it produces a leafy plant, and the leafy gametophyte alternates with the leafless sporophyte.

Anthoceros.—This little Liverwort has received a great deal of attention because many think that the Ferns have come from some such form. It is widely distributed. Look in ruts which wheels have cut into the ground in woodlands; deep footprints of horses and cattle may be lined with it; look in grass among bushes in moist meadows; banks of streams, especially clay or shale banks, may yield it in abundance (Fig. 207).

The antheridia and archegonia are rather peculiar but, as usual, a sperm fertilizes an egg, which soon develops into a mature sporophyte. This sporophyte is long and slender and even a smaller part of it produces spores than in any of the preceding Liverworts (Fig. 208*A*). The spore region is shaped like a thimble, so that there is only a thin layer producing spores. The long slender sporophyte sheds spores at the top while young spores are developing lower down. If the foot could only become fastened in the soil and get food there, instead of remaining fastened to the gametophyte, it would be independent. This is the nearest approach to independence; no Bryophyte has an independent sporophyte.

CHAPTER XII

BRYOPHYTES (*Continued*)

MOSSES (MUSCI)

All of the Mosses are leafy and in many of them the leaf has a midrib, a character which easily distinguishes them from the leafy Liverworts, none of which have a midrib in the leaf. Most of the Mosses are erect, while nearly all the Liverworts are prostrate. In the Mosses the germinating spore does not grow directly into the leafy plant but produces a branching filament from which leafy shoots are developed; while in the Liverworts this filamentous stage is either short, with little or no branching, or is entirely lacking. The sporophyte in Mosses is more complex than in the Liverworts.

Mosses usually grow in dense tufts on damp ground or on logs; many grow on the bark of trees; a few grow on rocks; and a few grow in the water. They are more abundant in the forest than in the open, and more abundant in temperate regions than in the tropics.

Peat Moss (Sphagnum).—This Moss grows in wet places in temperate and tropical regions all over the world. In peat bogs, where it is generally more or less covered with water, it grows to a great length, and the dense upper layer protects the lower layers from decay. These lower layers may become hardened into the substance called peat. In colder regions, where peat reaches its best development, it is cut into blocks and used for fuel. Other plants and also animals, buried in peat bogs, are sometimes found beautifully preserved, especially if they have turned into stone.

On account of its remarkable power to absorb and hold water, Peat Moss is used extensively in greenhouses and nurseries. During the World War, it was used, to a limited extent, in surgery

The general appearance, and especially the leaf, is so characteristic that no other Moss is likely to be mistaken for it. Some of

the leafy branches stick out nearly straight from the main axis, while others hang down so close that they hide it (Fig. 209*A*).

In a very young leaf the cells are all alike; but, as the leaf grows, some of the cells become very large, lose their cell contents,

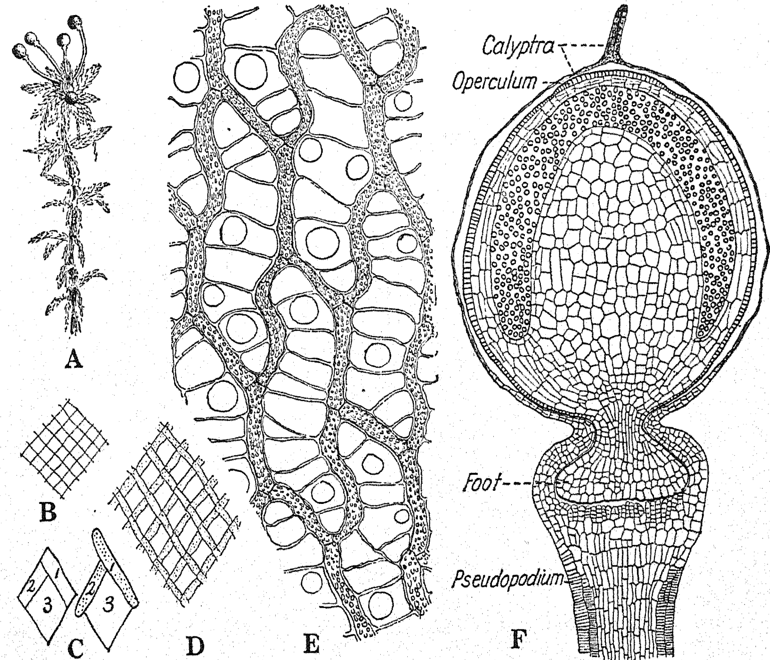


FIG. 209.—*Sphagnum*, Peat Moss. *A*, habit sketch of plant with sporophytes on long stalks (pseudopodia), natural size. *B*, part of surface view of very young leaf, while the cells are all alike, × 260. *C*, diagrams showing how the leaf cells divide, cutting off first the cells marked 1, and then cells marked 2. *D*, appearance of the leaf after these two cells have been cut off; the cells 1 and 2 are shaded. *E*, a few cells of the mature leaf; the cells 1 and 2 have chloroplasts; the diamond shaped cell of *C*, is colorless and has slender bands and some pores. × 300. *E*, sporophyte, nearly mature but still enclosed in the archegonium, the neck of which is seen at the top, while the lower part encloses the sporophyte; below the spreading foot is the upper part of the pseudopodium. × 24.

and develop slender but rigid bands, which keep the large empty cells from collapsing. The other cells, which are very regularly arranged, keep their living contents and do all the chlorophyll work of the plant. They grow somewhat in length, but remain narrow (Fig. 209*B* to *E*).

There are antheridia and archegonia, as in the Liverworts. A sperm from the antheridium fertilizes the egg in the archegonium, and the fertilized egg, without any resting period, develops into a mature sporophyte.

The sporophyte of the Peat Moss differs somewhat from those of the Liverworts (Fig. 209*F*). The spore-bearing part of it is

FIG. 210.—*Polytrichum* (*Squirrel Tail Moss*). About one-half natural size. (*From a photograph taken near Chicago by Miss Ethel Thomas.*)

thimble shaped and the top of the stem, just below the foot, elongates so that it looks as if it were the stalk of the sporophyte itself. It is called a *false foot* (pseudopodium). The real foot is comparatively small. At the top of the sporophyte is a circular cover (operculum), which comes off when the spores are ripe and allows them to escape.

For a long time during the growth of the sporophyte, it remains enclosed in the lower part of the archegonium, which stretches immensely as the sporophyte gets larger. The neck of the archegonium does not grow, but dries up and remains at the top. The enclosing part of the archegonium, consisting of the neck and much of the lower part, is called the *calyptra,* because it covers the sporophyte.

When the spores are shed, they grow into filamentous or flat structures which produce the leafy plant with which we started.

Life History of a True Moss. The Peat Moss differs in several ways from the rest of the Mosses, which are called True Mosses.

The erect leafy habit, which is prevalent in the group, is well illustrated by *Polytrichum,* often called the Squirrel Tail Moss (Fig. 210). *Funaria,* sometimes called the Cord Moss, is one of the first Mosses to appear in the spring, growing on damp ground, even along the sidewalks of cities. Sandy places, dumps, ash heaps, and the sides of ditches are likely to yield material. Probably no other Moss is so widely distributed and so well known all the world over as *Funaria.* Other mosses grow in various places, forming dense mats on trees, on logs, on rocks, and forming cushions on rich soil in the woods. A few of the commonest ones are shown in Fig. 211.

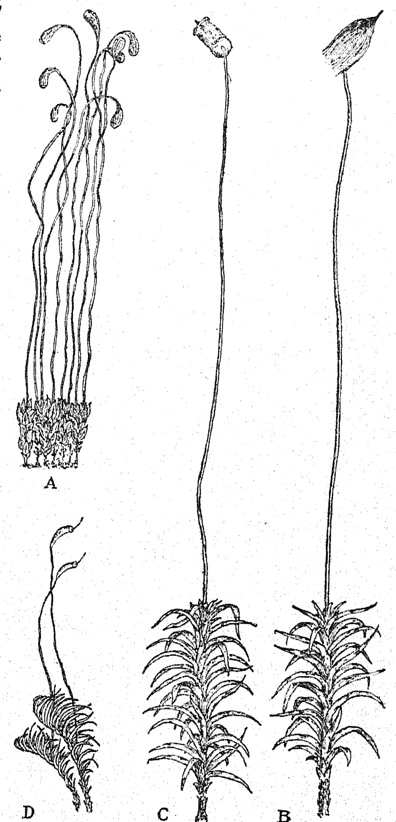


FIG. 211.—*Some Common Mosses.* *A, Funaria,* the *Cord Moss; B* and *C, Polytrichum*: *B,* with hairy calyptra which gives this moss its name; *C,* after the calyptra has fallen off; *D, Dicranum,* the Broom Moss. All natural size.

The leaves of the True Mosses are simple in outline, usually shaped more or less like a Willow leaf, only on a much smaller scale. The margin may be smooth or saw toothed (serrate) and there is generally a midrib (Fig. 212*A*, *B*).

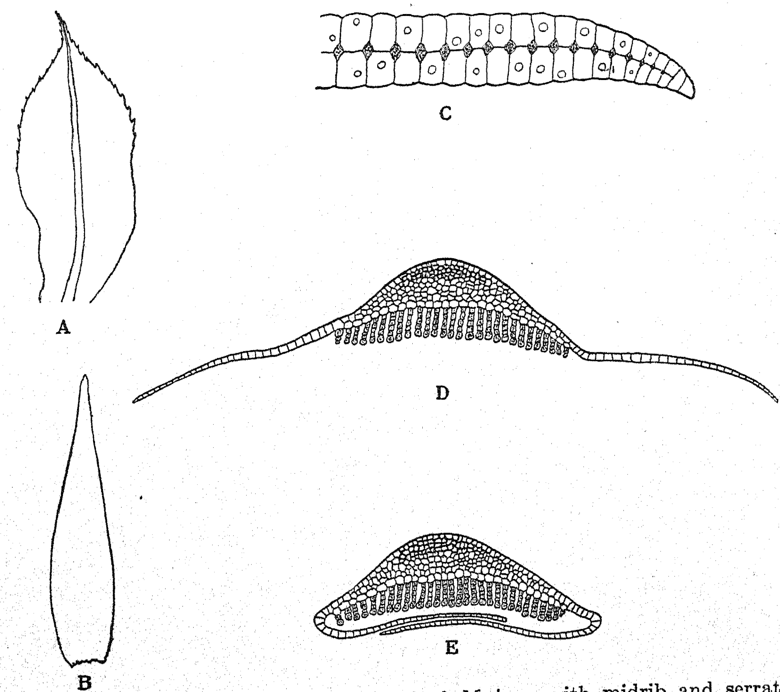


FIG. 212.—*Leaves of Mosses.* *A*, leaf of *Mnium*, with midrib and serrate margin, × 10; *B*, leaf of *Leucobryam*, with smooth margin and no midrib, × 6; *C*, cross-section of leaf of the White Moss (*Leucobryum*) with chlorophyll-bearing cells shaded, × 60; *D*, cross-section of leaf of *Polytrichum*, with chlorophyll-bearing cells exposed, as in wet weather; *E*, the same, with the edges of the leaf folded over and protecting the chlorophyll-bearing cells, as in dry weather, × 70.

Some Mosses have peculiar leaves. The White Moss (*Leucobryum*) has two kinds of cells, like *Sphagnum*, some inner cells, with chlorophyll, being protected by empty cells which gives the Moss its pale color (Fig. 212*C*).

The Squirrel Tail Moss has a still more peculiar leaf. As one looks at it under a pocket lens, it looks as if the leaf had several narrow midribs. A section of the leaf, under the microscope, shows that what appeared to be narrow midribs were really thin

plates of cells along the middle region of the leaf (Fig. 212*D*). In wet weather the margins of the leaf spread out flat; but when it is dry, they fold over the plates of cells, which contain most of the chlorophyll, and protect them (Fig. 212*E*).

Antheridia are borne in a cluster at the top of the leafy shoot (Fig. 213*A*).

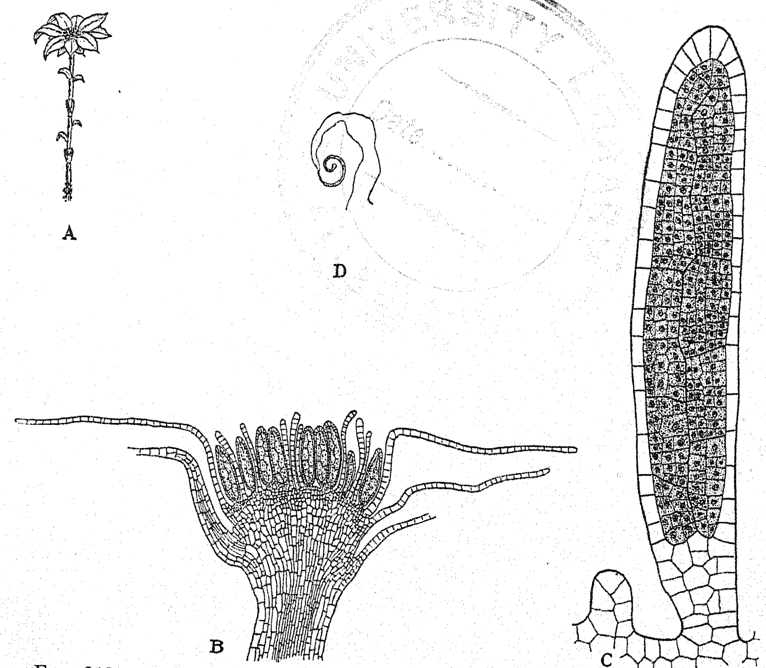


FIG. 213.—*Antheridia* of *Mosses*. *A*, flower-like antheridial head of *Mnium*, natural size; *B*, the same in longitudinal section, × 25; *C*, longitudinal section of an antheridium, × 240; *D*, a sperm, × 600.

When the antheridia are ready to shed their sperms, they have a yellowish or orange color and the little cluster of them, surrounded by leaves which spread out like the petals of a flower, can be seen without a lens. A thick longitudinal section through the cluster shows that the antheridia are numerous, and that many green filaments, about as long as the antheridia, are scattered among them (Fig. 213*B*). A thin section, highly magnified, shows about the same structure as we have already seen in *Marchantia* and other Bryophytes (Fig. 213*C*). Each cell of the

antheridium, except the protective layer on the outside, produces a sperm, which has two cilia and swims rapidly (Fig. 213*D*).

The archegonia are borne on a separate plant. They are also in a cluster at the top of the leafy shoot, but the leaves are folded over them more or less so that they are not as easy to find as the

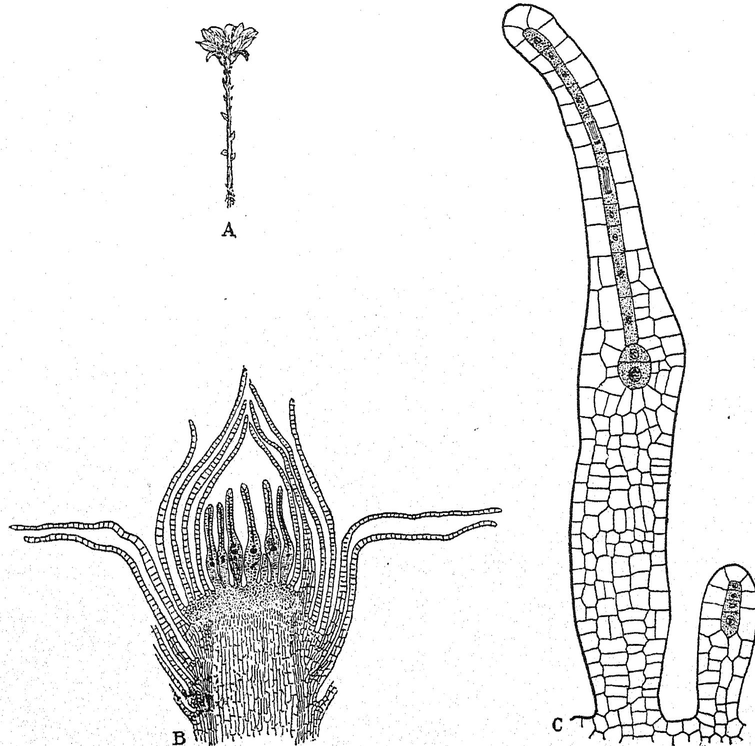


FIG. 214.—*Archegonia of Mosses.* *A*, archegonial head of *Mnium*, natural size; *B*, longitudinal section of the same showing six of the archegonia, × 25; *C*, single archegonium showing the egg, ventral canal cell, and the row of neck canal cells. At the right is a younger archegonium. × 240.

antheridia. The top of an archegonial shoot looks much like the top of one which has nothing but leaves; but a thick section, or the top of the shoot simply cut in two lengthwise, shows a cluster of archegonia, sometimes with green filaments mixed among them (Fig. 214*A*, *B*). A longitudinal section of a single archegonium shows a long neck, which is seldom straight, a row of eight or more

neck canal cells, a single ventral canal cell, and one egg (Fig. 214*C*).

As usual, the canal cells become mucilaginous, swell, break open the neck of the archegonium, and the sperms swim down through the mucilaginous liquid to the egg. One sperm enters the egg, and the fertilized egg grows until it becomes a mature sporophyte. While eggs in many of the archegonia are usually fertilized, the one which begins to grow first gets the food material and the rest dry up. So each leafy shoot usually has just one sporophyte.

The sporophyte of a Moss is much more complicated than that of a Liverwort and, since many of its most important features can be seen with a pocket lens, it is worth while to examine mosses in the field.

As the fertilized egg keeps dividing, it elongates so that it becomes a straight slender rod with the lower end fast in the bottom of the archegonium and the upper end stretching the upper part of the archegonium until it finally breaks, leaving the upper part on the top of the capsule, like a little hood (Fig. 215*A*, *B*). The part left on top is called the *calyptra*, because it covers the top of the capsule. The neck of the archegonium, dry and shriveled, is the topmost part of the calyptra. In some mosses the calyptra looks like a little scale and it drops off early; in others, it is conspicuous and stays on a long time. The calyptra shown in Fig. 211*B* is so large and hairy that it gives the moss its name, *Polytrichum*, meaning many hairs; and its common name, Squirrel Tail Moss, is also given on account of the hairy calyptra.

The sporophyte consists of a stalk with a capsule, or spore case, at the top (Fig. 216). If you moisten the stalks of Funaria a little, you will see a remarkable twisting and squirming. This moss is called *Funaria hygrometrica*, the *Fun-* meaning a little rope, the *hygro-* meaning water, and the *-metric-* meaning measure. So the whole name means a little rope which measures water, or which reacts to water. The movements scatter the spores more widely.

The capsule contains innumerable spores. Near the top of the capsule is a little red ring which a keen eye can see without a lens, but which is very clear and sharp under a pocket lens. The ring (*annulus*) is the lower part of the cover (*operculum*),

which is like a tiny cap, covering the top of the capsule and, for a while, protecting the structures underneath.

Just beneath the operculum of a ripe moss is a very beautiful and very complicated structure called the *peristome,* a word

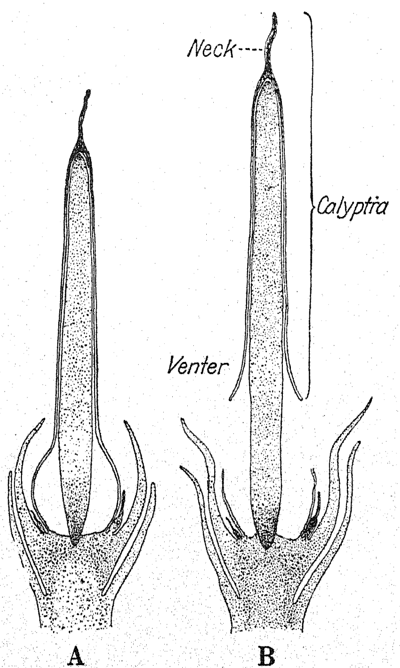


FIG. 215.—*Funaria.* *A*, a young rod-like sporophyte still enclosed in the archegonium; *B*, the elongation of the sporophyte has ruptured the archegonium, carrying up the top of it, with the neck, as the calyptra. × 15.

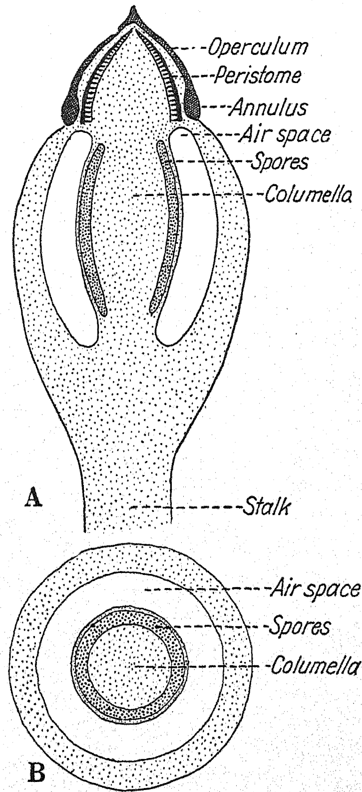


FIG. 216.—*Sporophyte of a Moss.* *A*, longitudinal section showing the principal parts; *B*, a cross-section. × 30.

meaning around the mouth. The peristome consists of "teeth" in a circle around the mouth of the spore cavity in the capsule. When the spores are ripe, the operculum falls off, bringing into sight the beautiful peristome beneath it (Fig. 217). The peristome looks like a tiny wheel, smaller than any wheel in a watch,

with the teeth as regularly arranged as the spokes in a wheel. The number of teeth is very regular—4, 8, 16, 32, or 64. *Funaria*, and many others, have 16; *Polytrichum* has 64.

The teeth of the peristome help to scatter the spores.

A section of the top of a Moss sporophyte, a little while before the spores are ripe, shows how much more complicated it is than the sporophyte of a Liverwort (Fig. 218).

When the spores are shed, they may rest for some time, but when they germinate they produce a branching filamentous structure which might be mistaken for a green alga (Fig. 219).

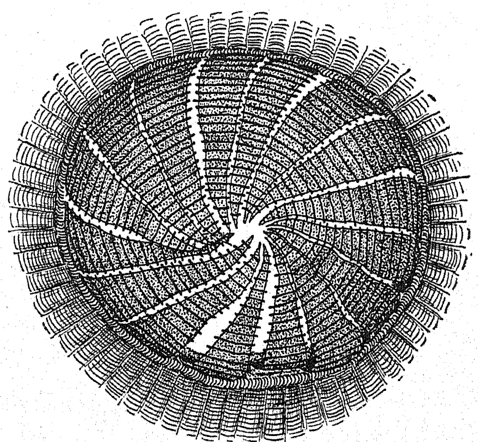


Fig. 217.—*Funaria hygrometrica.* Bird's-eye view of the peristome after the operculum has fallen off. × 35.

This alga-like stage is called the *protonema.* After a while leafy Moss plants begin to appear as buds on the protonema. As the Moss plants grow, they produce rhizoids, so that a plant will be attached to the filamentous protonema and will be producing filamentous rhizoids.

As the leafy Moss plants mature, they produce antheridia and archegonia, a sperm fertilizes an egg, which grows into a mature sporophyte, and the life cycle is complete.

In addition to the life history, as it has just been described, some Mosses have gemmae, like those in *Marchantia.* They are borne at the top of the leafy shoot where one expects to find antheridia and archegonia. One of these Mosses, called *Georgia*,

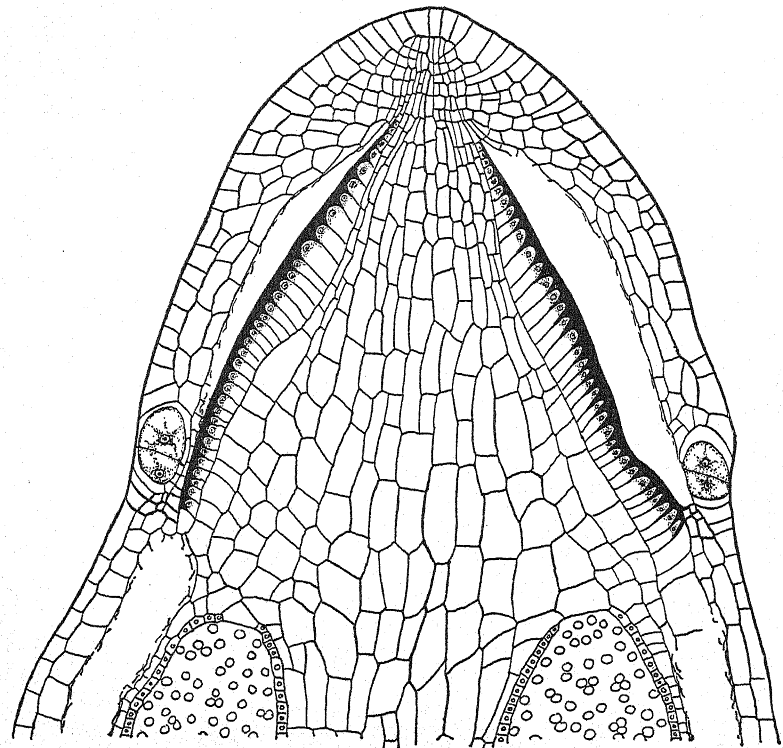


FIG. 218.—*Mnium*, longitudinal section of top of sporophyte showing two of the 16 teeth still covered by the operculum. × 115.

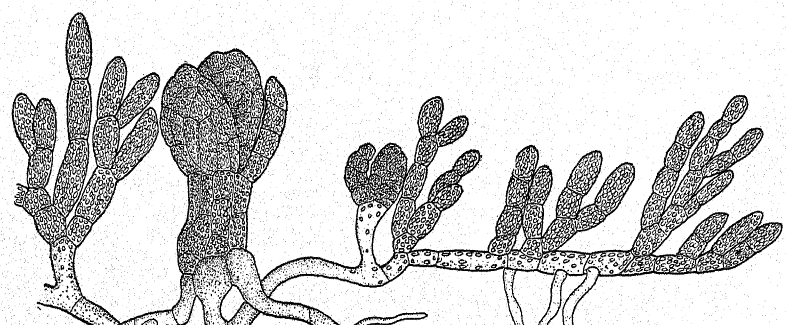


FIG. 219.—*Moss protonema.* Part of a vigorous protonema bearing two young moss plants. × 150.

is often found on rotten logs in swamps. This Moss is one of the few with four teeth in its peristome.

Some Mosses have still another method of reproduction. They form buds, or bulbils, looking at first as if they were to be leafy shoots, but soon getting brown and hard, so that they may resist unfavorable conditions for a long time. When conditions become favorable, the bulbils grow into new plants.

CHAPTER XIII

PTERIDOPHYTES

Pter- means feather and *-phyt-* means plant. Most of the Pteridophytes are Ferns and the group got its name because so many Fern leaves bear some resemblance to a feather.

The largest Bryophytes are larger than the smallest Pteridophytes; but most of the Pteridophytes are immensely larger than any Liverworts or Mosses. As you walk through the forest or drive along the road, the Ferns easily catch your eye; but you may not notice the Liverworts and Mosses unless you are looking carefully for them.

There are no leaves on any sporophyte in the Bryophytes; but, in the Pteridophytes, every sporophyte is leafy. There is no vascular system in any Bryophyte; but all Pteridophytes have a vascular system. There is no root in any Bryophyte; but all Pteridophytes (with a few exceptions which you are not likely to meet) have roots. In the Bryophytes the sporophyte, while it is usually green, never becomes entirely independent; it is always attached to the gametophyte and is parasitic upon it. In all Pteridophytes, the sporophyte, sooner or later, becomes entirely independent.

In the Bryophytes the gametophyte is the prominent generation; in the Pteridophytes the sporophyte is immensely larger, and the gametophyte soon dies, leaving the sporophyte rooted and leafy, an independent plant which may live and grow for many years.

With all these contrasting characters, it is easy to distinguish between Bryophytes and Pteridophytes.

In the United States there are three groups of Pteridophytes which we may call Lycopods, Horsetails and Ferns.

LYCOPODS

Some of the Lycopods are called Club Mosses, because they look like big Mosses and the spore-bearing part looks like a little

club. Some of them are called Ground Pines, because they look like Pine seedlings. Some look more like Ferns and some look like small Grasses.

Lycopodium.—Members of this genus suggested the common names, Club Moss and Ground Pine. These are the ones which are used for making wreaths to hang in windows at Christmas time (Fig. 220). There is a trailing rhizome, bearing erect shoots here and there, so that it is easy to take pieces several feet in length and coil them into a Christmas wreath.

Fig. 220.—*Lycopodium obscurum* var. dendroideum. Ground Pine, or Club Moss. About two-thirds natural size. (*From a photograph by A. F. Coventry.*)

The leaves are very small, generally less than ½ inch in length and most of them are even smaller. The margins are smooth and the tip is pointed. There are no lobed or compound leaves. The *pter*-, meaning feather, does not apply at all to the Lycopods. Other features of the life history give them their place here. If the Pteridophytes are divided into half a dozen large groups, all the groups, except one, have these small simple leaves, and we may call them Lycopods; but the remaining group, which we call Ferns, has large compound leaves and makes more display than the other five together. So it is quite proper that its most conspicuous feature, the feathery leaf, should give the group its name.

The stem of *Lycopodium* is very complicated, with a strong conducting strand in the center, and a slender strand connecting each leaf with the main strand. The root also has a strong conducting strand connected with that of the stem. The general appearance of a cross-section of the stem is shown in Fig. 221.

The spore-bearing part of *Lycopodium* is very different from anything we have met up to this point. The sporangia are

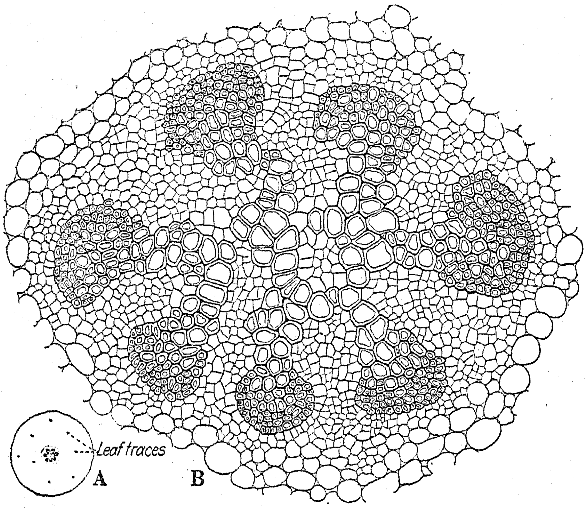


FIG. 221.—*Lycopodium lucidulum.* *A*, diagram of cross-section of stem showing the small woody portion, in the center and, in the cortex, much smaller strands (leaf traces) connecting the woody portion with the leaves; *B*, the central woody portion, × 110.

FIG. 222.—*Lycopodium complanatum.* *A*, longitudinal section of a cone showing sporophylls, each bearing one sporangium on its upper side, × 10; *B*, section of a single sporangium, × 150.

borne on the leaves and the leaves are crowded together into a *cone*. A leaf, bearing a sporangium, is called a *sporophyll* (spore leaf). In some species of *Lycopodium* the sporophylls look just like the rest of the leaves and are not any more crowded; but in most of the species the sporophylls are smaller than the rest of the leaves and are closely crowded into a cone (Fig. 220).

In the Lycopods there is just one sporangium on a sporophyll, and it is always on the upper side near the axis of the cone (Fig. 222*A*). A longitudinal section of the sporangium shows that it has a short stalk, a wall several layers of cells in thickness, and that it contains a large number of spores (Fig. 222*B*).

The spores are produced in such abundance that they are collected and sold at the drug store as *Lycopodium powder*. They are used in surgery and serve somewhat the same purpose as talcum powder. Along one of the roads through the Black Forest, in Germany, the yellow spores of *Lycopodium* are shed in such abundance that the road is called The Yellow Way.

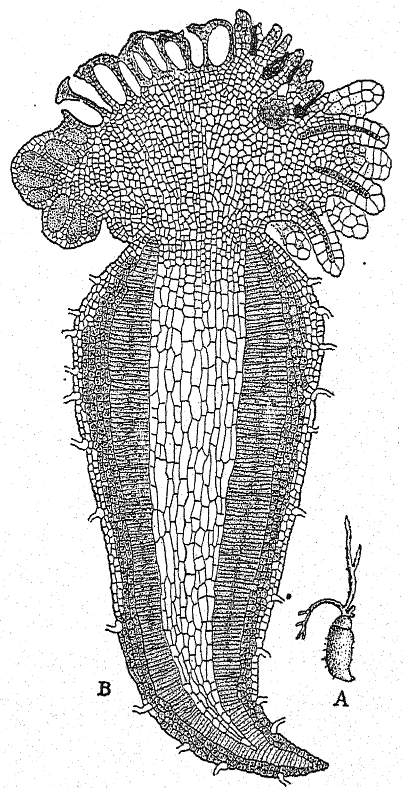


FIG. 223.—*Lycopodium complanatum*. *A*, gametophyte, bearing an erect shoot and a root curved over to the left. The whole structure, at this stage, is underground, × 2. *B*, longitudinal section of a gametophyte somewhat younger than the one shown in *A*; some antheridia at the upper left; in the middle, some antheridia which have shed their sperms; some archegonia at the right and also one young embryo. In the lower, turnip shaped part, the shaded cells are the ones which contain the fungus. × 20. (*After Bruchmann.*)

In spite of the abundance of spores, no one in America has ever succeeded in germinating them; and, in Europe, only one man has had any success. Strangely enough, he was not a pro-

fessor of botany in a great German university but a teacher of mathematics and physics in the high school of a little town near the Black Forest. But the spores do germinate and several people have found the gametophytes, with their antheridia, archegonia, and young sporophytes (Fig. 223).

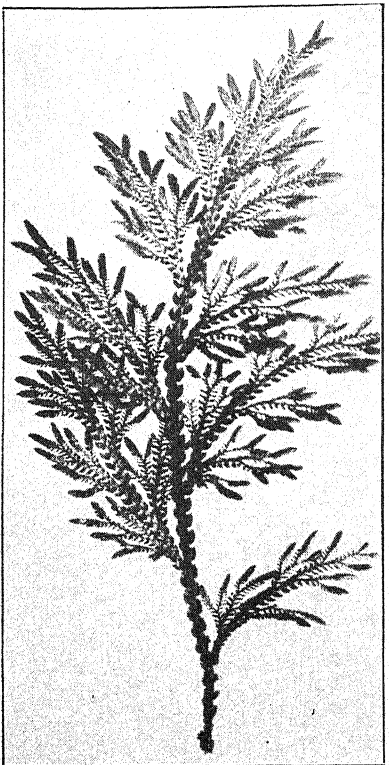


FIG. 224.—*Selaginella.* A branch with numerous cones at the tips of the smallest branches. About two-thirds natural size. (*From a photograph by by W. J. G. Land.*)

In nearly all the species of *Lycopodium* the gametophyte grows underground, an inch or more below the surface. It is thick, fleshy, and colorless. Having no chlorophyll, it is entirely dependent and lives, as a saprophyte, upon decaying material. There is always a fungus in this gametophyte, and the gametophyte cannot live without it. While Fungi cause most of the worst diseases of plants, many plants not only suffer no harm from the Fungi but cannot live without them.

Selaginella.—Most of the Lycopods belong to the genus *Selaginella.* Nearly all of them are tropical, but a few of them grow in the United States. One of the largest of our forms grows in Texas and is called the Resurrection Plant, because it can dry up until it looks dead and then become bright green in a few hours when placed in a dish of water. There are several species in various parts of the world which behave in this way. While *Selaginella,* in our country, is rare and we seldom see it in the field, some of the tropical species are very familiar in park greenhouses, where they form the beautiful mossy carpets in fern rooms and palm houses.

Selaginella branches profusely and has small, simple leaves, but the branches are so regular that the plant looks as if it were made up of compound leaves, like some delicate Fern (Fig. 224). The leaves are often of two kinds, larger leaves on the back and smaller ones on the underside.

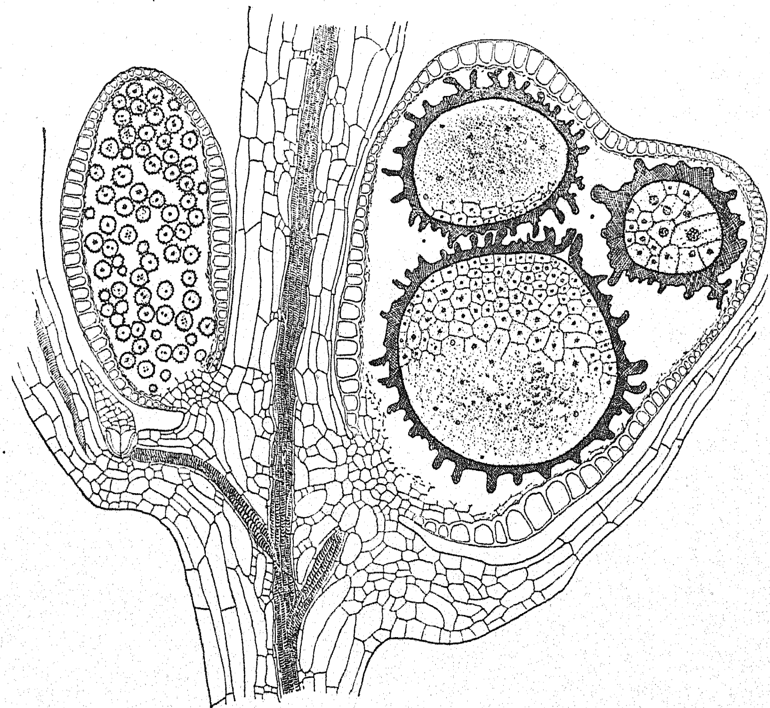


FIG. 225.—*Selaginella apus.* Section of part of cone showing a microsporangium with numerous microspores at the left, and a megasporangium with three of the four megaspores at the right. Female gametophytes are developing inside the three megaspores. × 80.

The sporophylls are smaller than the rest of the leaves and are crowded into cones. In *Lycopodium* all the sporangia and spores are alike; but in *Selaginella* the sporangia and spores are of two kinds. When you break a cone of *Selaginella*, it is easy to see that some of the sporangia are reddish and others are yellowish. The reddish sporangia, which are usually in the upper part of the cone, are called *microsporangia*, because they contain small

spores; and the yellowish ones, which are usually in the lower part of the cone, are called *megasporangia,* because they contain only four large spores. The small spores are called *microspores* and the large ones *megaspores.* A plant which has microspores and megaspores is said to be *heterosporous* (different spores), meaning that the spores are different in size. In *Lycopodium* all the spores are of the same size. Such a plant is *homosporous* (same spores) and the word means that the spores are the same in size. Figure 224 shows a large number of cones at the tips of the branches. The relative sizes of the microsporangia and megasporangia, with their microspores and megaspores, are shown in Fig. 225.

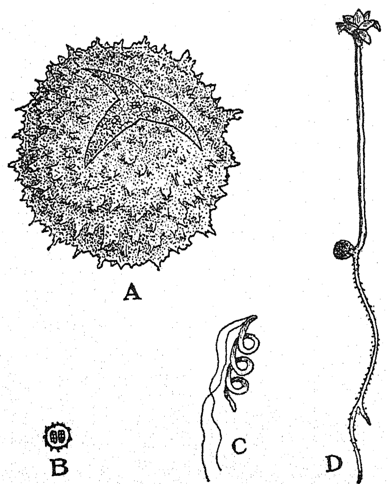


FIG. 226.—*Selaginella.* *A*, mature megaspore cracked open and showing five archegonia, $\times$ 60; *B*, section of a microspore drawn to the same scale; *C*, a sperm, $\times$ 1000; *D*, a sporeling, $\times$ 4.

When the microspore germinates, it does not behave like the spore of a Moss or like that of *Lycopodium;* for, when they germinate, the young plant immediately breaks the spore coat and comes out. In *Selaginella,* when the microspore germinates, it forms a very small new plant inside the spore coat. This small plant, inside the spore, contains an antheridium consisting of two groups of sperm cells surrounded by a sterile layer. Each sperm cell produces one sperm, which has two cilia, like the sperm of a Moss (Fig. 226). The antheridium swells enough to crack the spore coat and allow the sperms to escape.

When the megaspore germinates, it makes such a large crack in the spore coat that the archegonia can be seen with a pocket lens (Fig. 226*A*). It is important to note that the microspores and megaspores begin to germinate while they are still in their sporangia on the parent plant. In Fig. 225 the megaspores have germinated and formed many cells, while the spore coat is just beginning to crack open.

Both microspores and megaspores are shed from their sporangia, but the gametophytes, although exposed a little by cracks in the spore coats, never get outside the spores. In plants above the Pteridophytes the megaspores remain in their sporangia. They are never shed.

As usual, a sperm fertilizes an egg in the archegonium and the fertilized egg, nourished awhile by the food material inside the megaspore, forms a root, a stem, and a few leaves (Fig. 226*D*). By this time the root is firmly established in the soil, and the young plant has become independent.

Isoetes.—This plant, looking like a small tuft of grass, is called the Quillwort. It is found in many places in the eastern United States, but is not so common in the middle and western states.

It grows in wet places, along the borders of ponds and streams, on mud flats, on wet prairies, and some species are at their best under water. It is likely to be overlooked, even when one is within reach of it. The leaves are a few inches long—in some, a foot long—but its short stem is underground and the plant looks so much like the grass with which it is usually growing that it passes unnoticed.

When in fruit—and it is generally in fruit—there is a sporangium at the base of each leaf. *Isoetes* is heterosporous, with the outer leaves bearing megasporangia and the inner ones bearing microsporangia. Nearly every leaf is a sporophyll, and the sporangia are the largest that have been found in living Pteridophytes, some of them reaching 3/8 inch in length. A megasporangium contains from 150 to 300 megaspores, and a microsporangium contains from 150,000 to 300,000 microspores. So, the megaspores are about 1,000 times as large as the microspores.

Where even a demonstration specimen is available, it is worth while to note the general appearance, for no other Lycopod has so large a leaf as *Isoetes*. The life history is about the same as in *Selaginella*.

CHAPTER XIV

HORSETAILS (EQUISETUM)

More than a hundred million years ago, when coal was being formed, there were forests of plants with jointed stems and cycles of jointed branches growing in the swamps of that far-off time (Fig. 227). Many of these plants reached a height of 30 or 40 feet.

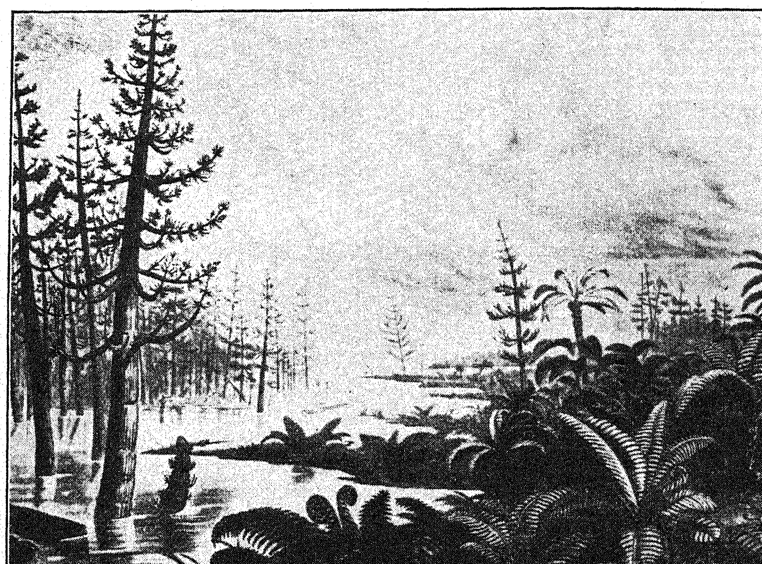


FIG. 227.—Reconstructed landscape of the Carboniferous Age. (*After Zittel.*)

Today, the surviving remnants of this strange group still grow in swamps or moist places, but there are no such large forms as those of the Coal Age. The living species in the United States range from one to six feet in height. A few in the tropics are taller, but a stem an inch in diameter is rare. A Pacific Coast *Equisetum*, the largest in our country, is shown in Fig. 228. Another, rather common, especially in the middle and eastern

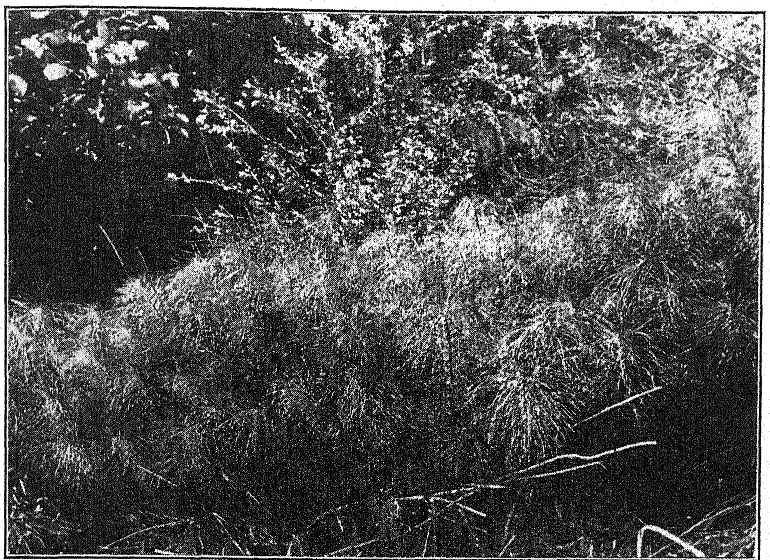


FIG. 228.—*Equisetum telmateia.* At the Puget Sound Biological Station at Friday Harbor, Wash.

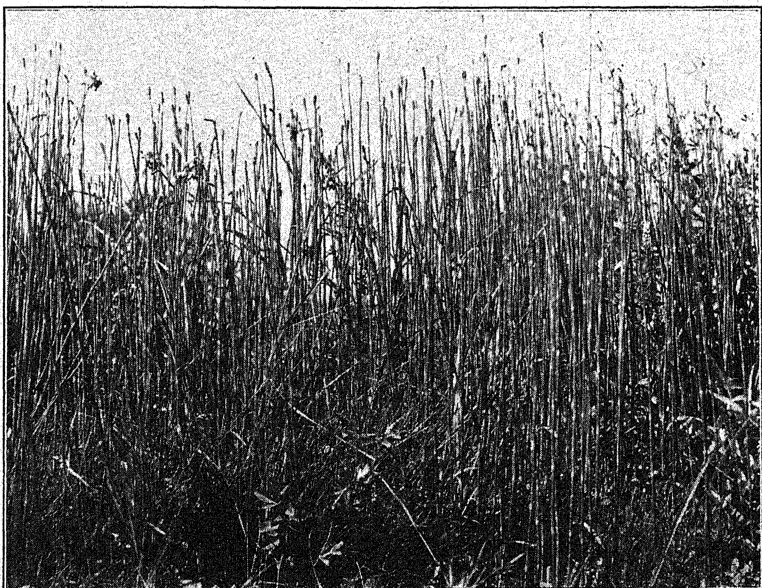


FIG. 229.—*Equisetum hyemale, The Scouring Rush.* Near Chicago.

states, is shown in Fig. 229. The first of these two figures illustrates the profusely branching type, and the second the rushlike type. Most of them are rough, like sandpaper, and have been called Scouring Rushes, because the early settlers used them to scour kettles. Why they should be called Horsetails is not very clear.

A smaller species of the branching type is very common along railways, because it needs water, but it also needs rapid drainage. A railroad gets as much water as any other place but must be built for rapid drainage to keep its ties from rotting and also to keep the roadbed solid. When section gangs see *Equisetum* along the track, they know that the drainage is good.

The structure of the stem is very characteristic. In nearly all of them it is as beautifully and regularly fluted as a Greek column. In some there are two rows of stomata, under a pocket lens looking like rows of white dots, in each depression between two of the ridges; in others the stomata are scattered.

The leaves are reduced to mere scales, which occur in cycles at the nodes. The lower parts of the leaves are united into a tube, but the tips are free and pointed and are generally dry and dark colored. Only the bases of the leaves do chlorophyll work. The whole stem is green and does nearly all the chlorophyll work for the plant.

In cross-section the stem is even more characteristic than in surface view (Fig. 230). The ridges and depressions are easily seen. The ridges consist of thick-walled cells while the depressions have thinner walled cells containing most of the chlorophyll. The stomata open into the chlorophyll region.

The stem is hollow except at the joints, where there are strong partitions. Under each depression, or valley, there is a cavity called the *vallecular cavity;* and under each ridge there is a smaller cavity called the *carinal cavity*, because the ridge is like the carina, or keel of a boat. There is very little wood in this stem. The earliest wood occupied the position of the carinal cavity and dropped out when that cavity was formed. The rest of the wood, which you may have trouble in finding at all, lies along the sides of that cavity.

Although this stem has scarcely any wood, it is very strong for its weight. Where the greatest strength with the least weight

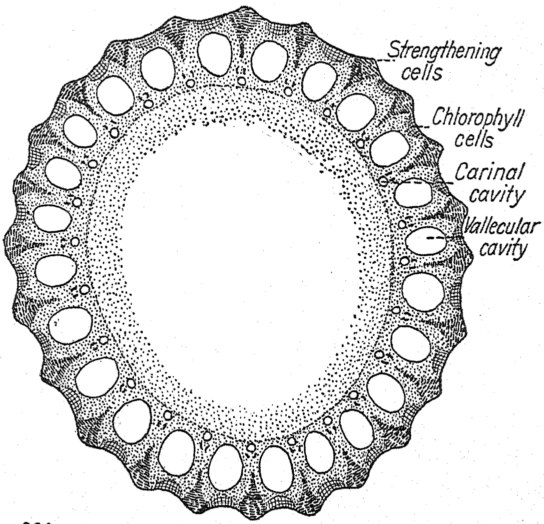


FIG. 230.—*Equisetum hyemale.* Cross-section of stem, × 10.

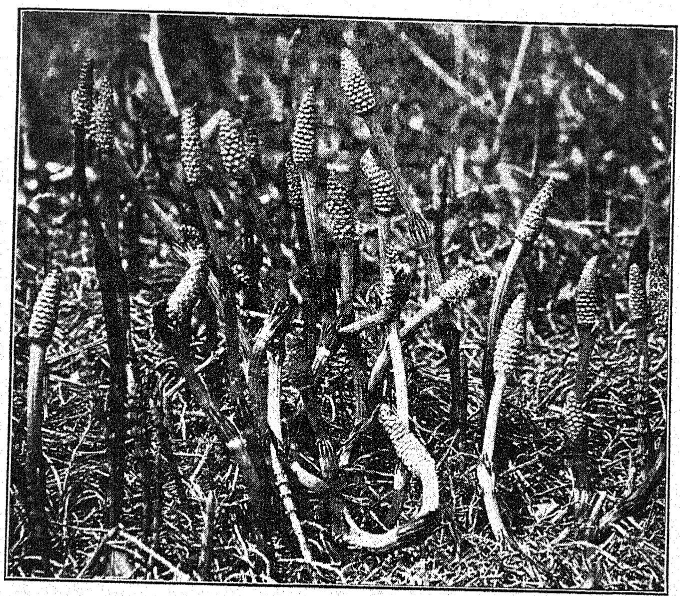


FIG. 231.—*Equisetum arvense.* Early spring condition, with cones. One-half natural size.

is desired, builders might get useful hints from a study of the *Equisetum* stem, especially in planning columns.

The spores of *Equisetum* are borne in cones. In the form which grows along the railroad, a weak yellowish shoot, usually three to six inches in height and not branching at all, comes up early in the spring (Fig. 231). After the spores have been shed the weak shoot decays and a strong, green, branching shoot comes up from the same rootstock and lives until winter. Before winter sets in, the cone for the next season is fully formed and, close to it, there is a strong bud for the branching shoot.

Most species have their cones on the tips of the vegetative shoot, and the cones appear late in the spring or in early summer (Fig. 229).

Each cone has a large number of sporangia hanging down from shield-shaped structures, which are usually called sporophylls. The sporangium contains a large number of spores, which are all of one kind; so Equisetum is homosporous.

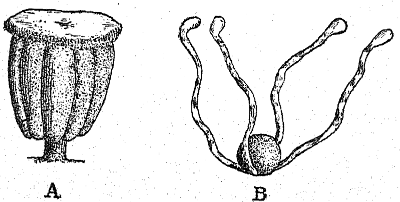


FIG. 232.—*Equisetum arvense.* *A*, sporangia hanging down from the shield-shaped top of the "sporophyll," × 10; *B*, spore with the four ribbon-like bands (elaters), × 150.

The outer spore coat splits in a peculiar way and pulls loose from the spore, except at one point, so that each spore has attached to it four slender ribbons, which spread out or wrap themselves around the spore (Fig. 232). If a mass of the dry spores is dampened a little, there is a squirming and twisting which makes an interesting sight under the microscope. Dry spores may be kept for years and used repeatedly for this experiment, which works as well after the spores are dead as when they are alive.

When the spores are shed, they look green because they contain so much chlorophyll. They germinate well the day they are shed and for a few days afterward; then there is less and less germination, and, after a couple of weeks, there may be no germination at all. Any spores which contain enough chlorophyll to make them look green are likely to be short lived.

The gametophytes produced by the germinating spores are small. The antheridia may appear when the gametophyte is

not more than one-sixteenth of an inch long; and, when it is one-eighth of an inch long, the archegonia may be fully developed. Antheridia and archegonia are borne on the same plant, but the antheridia come first (Fig. 233).

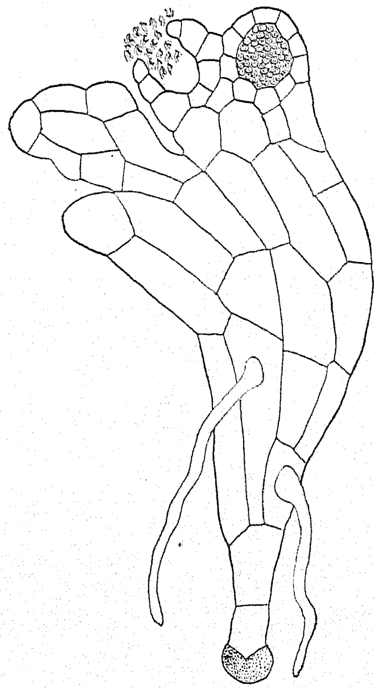


FIG. 233.—*Equisetum arvense.* A prothallium with two antheridia. The sperms are escaping from the one on the left. × 150.

A sperm fertilizes an egg and the fertilized egg grows into a new *Equisetum* plant which, for a while, is attached to the gametophyte; but the root becomes established while the gametophyte decays, leaving the Equisetum plant independent and able to take care of itself.

Equisetum is perennial and some species remain green throughout the winter, while others die down to the ground and the rhizome, with strong buds, starts the growth the next spring.

CHAPTER XV

PTERIDOPHYTES

FERNS

The beauty of their leaves has given the Ferns their popularity as decorative plants in the home and in our park conservatories. In most of them the stem is underground, so that we see only the beautiful crown of gracefully drooping leaves, as it is familiar to everyone in the Boston Fern. Ferns add to the charm of woodland scenery (Fig. 234). In the tropics where they reach their greatest size and beauty, there are Tree Ferns 20 or 30 feet in height (Fig. 235). In tropical forests many ferns grow on trees, sometimes breaking down large trees with their increasing weight. The peculiar Stag Horn Fern, small specimens of which are often seen in greenhouses, is a familiar sight on the islands off Brisbane in Australia (Fig. 236).

Some of our most familiar Ferns are the Bracken Fern, the Maiden Hair Fern, the Christmas Fern, and the Cinnamon Fern.

The Bracken Fern is probably the best known and most widely distributed of all Ferns. In our middle states it seldom reaches a height of more than 2 or 3 feet; on our West Coast it is much larger, often reaching 10 feet in height and growing in such profusion that one can hardly walk through it (Fig. 237). In New Zealand it is even larger, sometimes reaching a height of 20 feet, covering great areas so densely that it is almost as difficult to clear the land for agriculture as it would be to clear it of trees. In that region prisoners from the penitentiary dig up the Fern and plant our American Larch; so that considerable areas in the northern part of New Zealand, especially mountain sides, are becoming forested with our well-known tree.

The Maiden Hair Fern is a delicate, beautiful, little Fern with shining black leaf stalks, seldom more than a foot high, growing in moist shaded places in woodlands. While it is a beautiful

plant in the forest, it does not grow well in the house, especially in a steam-heated house. In greenhouses both native and tropical species are always a feature of the Fern room.

FIG. 234.—*Ferns.* (*Polystichum munitum*) at the summer home of Prof. Ira M. Price, near Olympia, Wash.

The Christmas Fern gets its name because it is evergreen, always bright and fresh even in midwinter. It is common in the eastern and middle states and species resembling it are common in the western states.

The Cinnamon Fern gets its name from the cinnamon-colored leaves which bear the spores. They come up early in the spring,

before the foliage leaves appear, shed their spores and die, while the foliage leaves keep on growing (Fig. 238). This Fern is at its best in wet shaded places. It is a good one to dig up and set out on the shaded side of the house. Two kinds of leaves, with

FIG. 235.—*Tree Ferns* (*Cyathea medullaris*) at Owharoa, New Zealand.

the spore-bearing leaves very different from the foliage leaves, are common in Ferns. In some only the upper part of the leaf bears spores, as in the Christmas Fern and the Royal Fern.

The Grape Fern gets its name because the spore-bearing part looks like a bunch of little grapes (Fig. 239). Here, it is the two

lower leaflets, grown together, which bear the spores. Only one leaf is produced each year. A carefully prepared section

FIG. 236.—*Stag Horn Ferns* (*Platycerium grande* and *P. alcicorne*) on Stradbroke Island, near Brisbane, Australia.

of the bud, which is always underground, shows the young leaves which are to appear during the next three years. In autumn the leaf which is to appear aboveground the next spring, is well

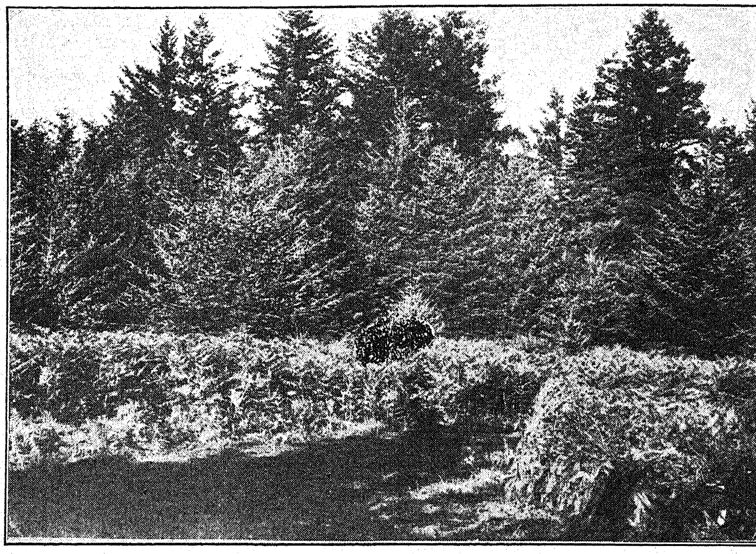


FIG. 237.—*Bracken Fern* (*Pteris aquilina*) at the Puget Sound Biological Station, Friday Harbor, Wash.

FIG. 238.—*The Cinnamon Fern* (*Osmunda cinnamomea*) near Chicago. The cinnamon colored, club-like leaves in the center give this fern its name.

developed and the grapelike part is easily seen. The leaves for the next two years are recognizable but do not look like leaves.

The Ferns of the United States are classified and described in books called *manuals*, which have *keys* to enable anyone to find the names of the plants. There are manuals of the northeastern, southern, and western states. After a study of the life history of a Fern, it will not be difficult to take a manual and find the names of the Ferns in one's locality.

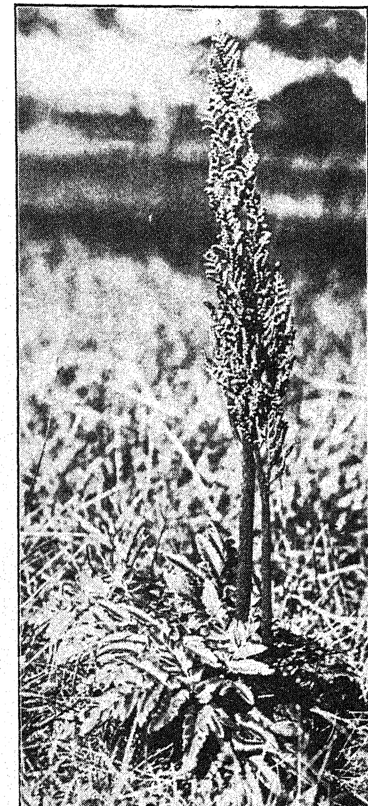


FIG. 239.—*The Grape Fern* (*Botrychium*). At Oberlin, Ohio. The round, clustered sporangia, like a bunch of grapes, give this fern its name.

The Life History of a Fern.—When the life history of a Fern is compared with that of a Moss, the most striking difference is that in the Fern the sporophyte is the conspicuous generation, with leaf, stem, and root, which make it independent; while in the Moss the gametophyte is the conspicuous generation and the sporophyte never has leaves or roots and never becomes an independent plant. In the Fern most people never see the gametophyte; while in the Moss they seldom see anything else. In the Fern the names are suggested by the sporophyte, as Christmas Fern, Stag Horn Fern, Walking Fern; while in the Moss the gametophyte usually suggests the name, as Peat Moss, White Moss, Tree Moss, Water Moss. But Mosses are so small that most of them do not have common names.

The Leaf.—The glory of a Fern is its leaf. Some leaves are very small and delicate, but some are very large. In temperate

regions, most of the leaves are 1 or 2 feet long; a few, like the Cinnamon Fern and Ostrich Fern, occasionally reach a length of 6 feet; and the leaf of the Bracken Fern, on our Pacific Coast, is often 10 feet long.

The largest leaves are found in the tropics where Tree Ferns have immense leaves, often 10 or 15 feet long. In the tropical

FIG. 240.—*Angiopteris.* At Babinda, in northern Queensland, Australia. The leaves sometimes reach a length of nearly 20 feet.

rainy forests of Eastern Australia, huge Ferns with thick stocky stems have leaves 20 feet long and leaf stalks as large as a man's arm (Fig. 240).

The leaves generally form a crown or nest at the top of the stem. In most Ferns the leaves are compound and of the pinnate type, the feature which gives the name, Pteridophyte, to the whole group. In many, and especially in the larger Ferns, the leaflets (pinnae) are themselves compound; so botanists say the leaves are twice pinnate, or *bipinnate.* In a few there is still another division and the leaf is said to be thrice pinnate. In some like the Walking Fern and Bird's Nest Fern, the leaves

are simple. Various kinds of leaves are shown in Figs. 234 to 240.

The young leaves are coiled in the bud and they unroll as the bud opens (Fig. 241). The coiled position is a great protection while the leaves are young and tender.

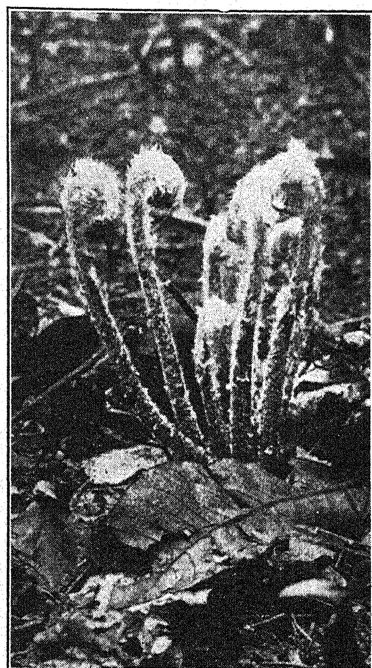


FIG. 241.—*Cinnamon Fern* (*Osmunda cinnamomea*). Young leaves showing the coiled (circinate) vernation. (*From a photograph by A. L. Princehorn.*)

The veins of a Fern leaf are almost always forked. In some they fork two or three times. The veins are so easily seen and are so characteristic, that they help in finding the names of Ferns.

The microscopic structure of the Fern leaf is much like that of a Lily or a Lilac. There is an epidermis above and below, with softer tissue between, and the stomata are nearly always in the lower epidermis.

The Stem.—In most ferns the stem is underground and is called a rhizome. It is usually horizontal, but in some, like the Grape Fern, it is vertical. In some, like the Cinnamon Fern, the rhizome is densely covered by old leaf bases; while in others, like the Bracken Fern, it is smooth.

In the Tree Ferns the stem is erect and may reach a height of 20 to 30 feet. In dense forests, where the stem is likely to be tall and slender, it may even reach a height of 50 feet. Typical Tree Ferns are shown in Fig. 235.

The structure of the Fern stem should be studied by everyone who wants to know anything about the life of the higher plants. In such larger plants there is a great division of labor. Some structures protect, some absorb, some conduct the absorbed material to places where the crude foostuff is manufactured

into usable food, and some conduct the manufactured food to places where it is used. Besides, some structures reproduce the plant.

The Conducting System.—The principal feature of the stem is the conducting system. Botanists call it the *stele* (pronounced

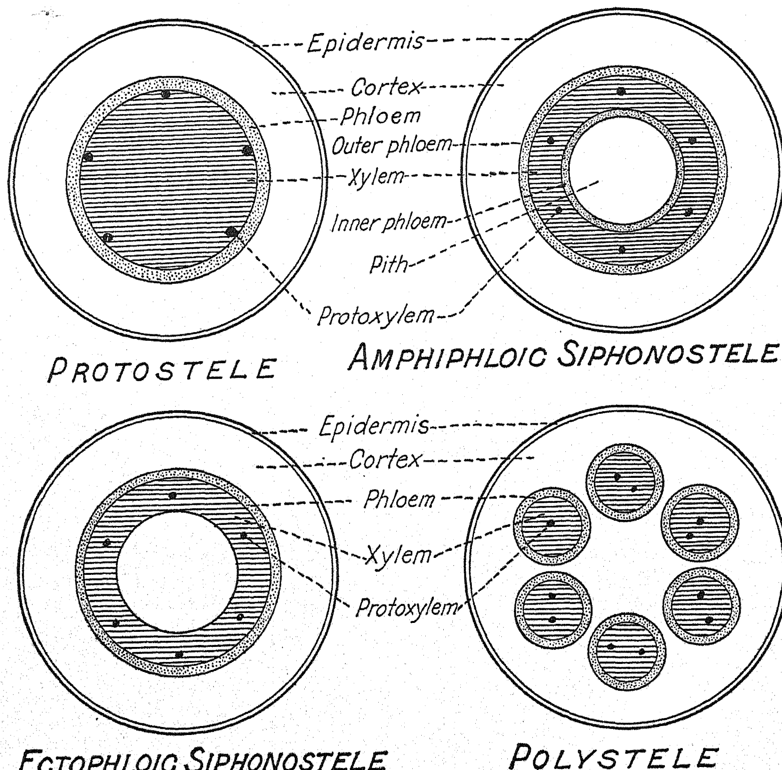


FIG. 242.—Diagrams of Steles. Protostele of *Lepidodendron*. *Gleichenia* is like it, except that the protoxylem is mesarch. *Amphiphloic* siphonostele of *Adiantum* or *Dicksonia*. Ectophloic siphonostele of *Osmunda*. Polystele of *Polypodium* and many other ferns.

steal). It is worth while to learn the different kinds of steles, with their names, for all the Pteridophytes and all plants above them have steles of one kind or another.

The principal features of the stele are the wood, which we call *xylem*, and the *phloem*. Outside the stele there is a *cortex;* and

inside it there is often a *pith*. The names of the different kinds of steles depend upon the positions of these parts.

In a *protostele* the xylem is in a solid piece, surrounded by phloem. In an *amphiphloic siphonostele* there is a pith in the center, and the xylem has the form of a hollow cylinder, with

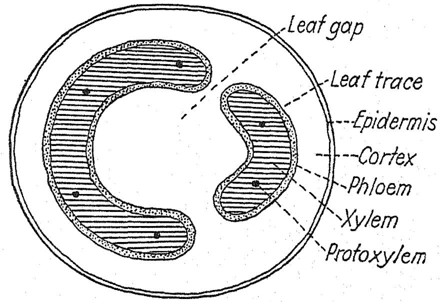


FIG. 243.—Diagram of a leaf gap and leaf trace (*Adiantum*).

phloem on both sides. In an *ectophloic siphonostele* there is a pith, and the xylem has the form of a hollow cylinder, but there is phloem only on the outside. In the *polystele* there are several strands, each one a protostele, and they are generally arranged

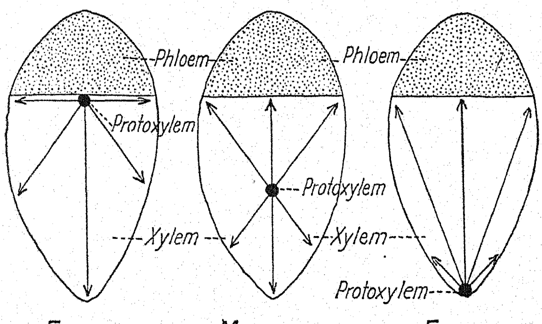


FIG. 244.—*Diagrams of protoxylem.* Exarch, *Lycopodium* and many ancient plants. Mesarch, stems of most ferns. Endarch, stems of all seed plants.

in a circle, so that there is a pith in the center and a cortex outside. *Gleichenia* has a protostele; *Adiantum* (the Maiden Hair Fern) has an amphiploic siphonostele; *Osmunda* has an ectophloic siphonostele; and *Polypodium*, Pteris and many others, have polysteles. These various types of steles are shown in Fig. 242.

When a leaf is formed, it makes a break in the stele. This break is called a *leaf gap*, and the strand which connects the stele and the leaf is called the *leaf trace* (Fig. 243).

In the young stem the xylem does not begin to harden all over at the same time but begins to harden at some spot and the hardening spreads. The spot where the hardening starts is

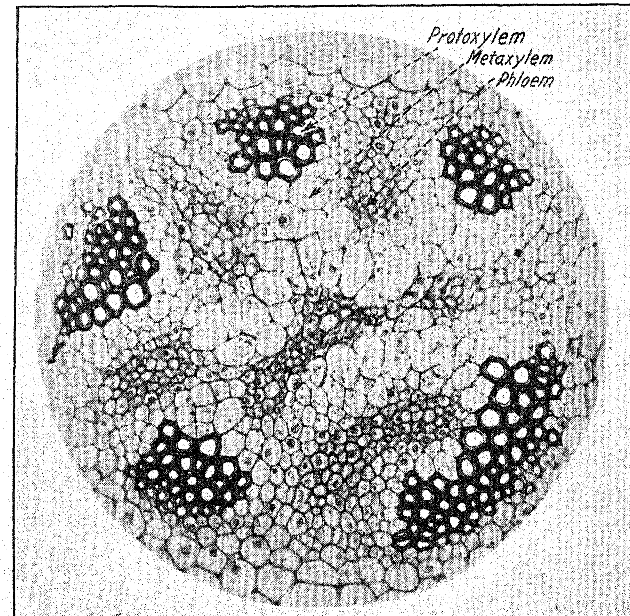


FIG. 245.—*Lycopodium lucidulum.* Cross-section of stem, showing protoxylem with walls already thickened, while the walls of the rest of the xylem (Metaxylem) are still thin walled. × 360. (*From a photomicrograph by Sedgwick.*)

called the *protoxylem*—the first xylem. If the protoxylem is at the outside of the xylem area, the stele is *exarch* (beginning outside). If the protoxylem is on the inside, next the pith, the stele is *endarch* (beginning inside). If the protoxylem is anywhere between the outside and inside, the stele is *mesarch* (beginning in the middle). The three positions are shown in Fig. 244.

This may seem difficult, but if sections are cut and stained at the place where the protoxylem is hardening, the protoxylem is easily recognized; for its cell walls are thicker and they stain

deeply, while the walls of the rest of the xylem are thin and may not stain at all. By cutting sections an inch or more back from the tip of the stem and then cutting closer and closer to the tip, one will come to the place where the protoxylem is beginning to thicken. A photomicrograph of the section of the stem of *Lycopodium*, taken when the protoxylem has hardened but while the walls of the rest of the xylem are still thin, shows how easy

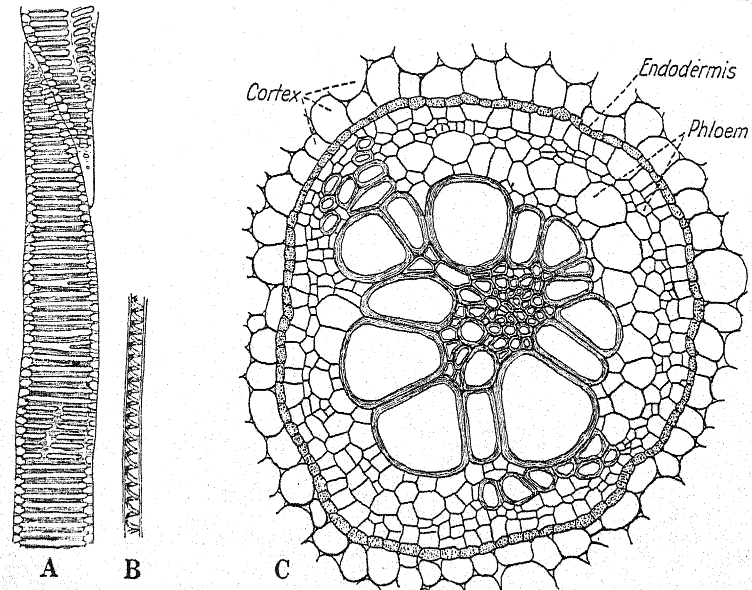


FIG. 246.—*Bracken Fern* (*Pteri's aquilina*). *A*, parts of two scalariform tracheids; *B*, part of a spiral vessel of the protoxylem; *C*, cross-section of a single bundle of the rhizome. The large, shaded cells are the scalariform tracheids of the metaxylem. The smallest cells in the center are the protoxylem. × 150.

it is to recognize the protoxylem if the section is taken at the right place (Fig. 245). Here, the protoxylem of the stem is exarch; in most Ferns it is mesarch; but in a few, like the Grape Fern, it is endarch. The rest of the primary wood is called *metaxylem*.

The wood of Ferns is made up, almost entirely, of elongated cells, pointed at both ends and marked with bands which look like the steps of a ladder. They are called *scalariform* (ladder form) *tracheids* (Fig. 246). The protoxylem has spiral thickenings on its walls.

The phloem is outside the xylem, but its walls have no such conspicuous markings, and it is not always easy to recognize. The crude food material goes up in the xylem to the leaf, where it is manufactured into usable food, which is then carried by the phloem to parts of the plant where it is needed.

The Root.—The structure of a root is comparatively simple and is very much the same in all plants which have roots. The protoxylem is exarch, and the xylem, in cross-section, is generally arranged like the spokes of a wheel, so that the protoxylem is at the tip of the spoke (Fig. 247). There may be two, three, four, five, or more spokes, and the phloem is between the spokes.

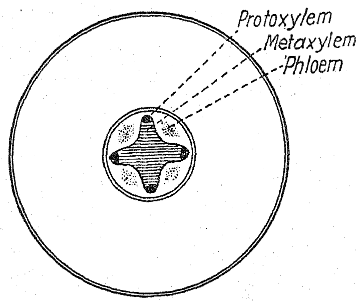


FIG. 247.—Diagram of a cross-section of fern root (Botrychium). × 12.

The Sporangium.—The sporangia of Ferns are borne on the underside of the leaves or, occasionally, on the margins. In a few cases they occur singly, but almost always they are in groups, called *sori*. A sorus is usually protected by a covering called the *indusium;* but in many Ferns the sorus has no such protective covering. Sori with and without indusia are shown in Fig. 248.

In many Ferns some of the leaves are given over entirely to the production of sporangia, as in the Cinnamon Fern. Such leaves are likely to be smaller than the foliage leaves and usually die after the spores are shed. Most Ferns have their sporangia in sori on the underside of leaves, which look just like the leaves which have no sporangia.

Recall *Riccia*. All of the sporophyte, except a protective layer of cells on the outside, produces spores. In *Marchantia* much less than half of the sporophyte produces spores. In the Mosses only a small part of the sporophyte produces spores, while a very much larger part is doing other work. In the Fern only an extremely small part of the sporophyte produces spores. Unless one keeps in mind forms like *Riccia, Marchantia,* and Mosses, when he comes to the sporangia of a Fern, he is likely to think they just happened that way. But, in the development

of the plant kingdom, a constantly increasing proportion of the plant is doing vegetative work, while a constantly decreasing proportion is devoted to the production of spores.

The sporangia of all the Ferns, except the Water Ferns, have only one kind of spore; they are homosporous, like *Lycopodium* and *Equisetum*.

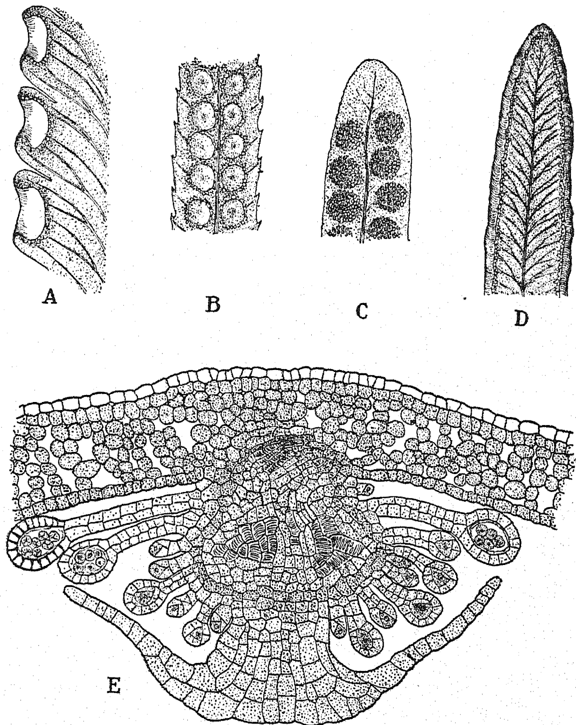


FIG. 248.—Sori of Ferns. *A*, Maiden hair Fern (*Adiantum*), × 3; *B*, Shield Fern (*Aspidium*), × 2; *C*, Polypody (*Polypodium*), × 2; *D*, Bracken Fern (*Pteris*), × 2; *E*, section of leaf of *Cyrtomium*, a very common greenhouse fern. Sporangia of various ages are covered by the umbrella-like indusium. × 90.

The structure of an ordinary sporangium, like that of the Bracken Fern, Christmas Fern, or Boston Fern, is shown in Fig. 249. There is a ring (annulus), which acts like a spring and breaks the sporangium open and scatters the spores when they are ripe. The ring has a reddish color when the sporangium is half ripe, but turns to a brick red or warm brown when the spores

are ripe. When the sporangia are just ready to shed spores, one can put them under the microscope and see the ring fly back and the spores shoot out.

The Gametophyte.—The spore is the first cell of the gametophyte generation. In most Ferns the spores germinate as soon as they are ripe, but, unless they are green, they may live for months after they are shed. The gametophyte of a Fern is usually called a *prothallium.*

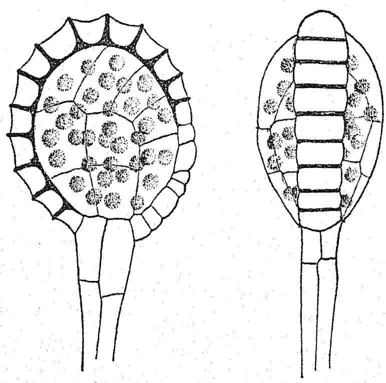


Fig. 249.—Sporangia of *Pteris: A*, side view; *B*, back view. × 360.

When the spore germinates, the spore coat breaks and the contents of the spore come out, forming a filament (Fig. 250*A*). The filament then becomes broader and ribbon-like and, finally, becomes more or less heart shaped. The gametophyte soon becomes several cells thick in the middle region, but remains only one cell thick at the sides. Even the two-celled filament shows some chlorophyll in the outer cell, and the cells formed later have a deep green color. Numerous cobwebby rhizoids attach the gametophyte to the soil.

Gametophytes in various stages of development can usually be found on flower pots in greenhouses, but a sure way to get them in abundance is to sow the spores, as indicated in the laboratory directions at the end of the book.

Antheridia appear early, sometimes when the gametophyte is a small filament; and when it becomes a flat plate one-sixteenth of an inch wide, it may have dozens of antheridia (Fig. 250*B, C*).

The antheridium starts as a hemispherical cell which elongates a little and then divides, forming an outer, almost spherical cell and a basal cell. The outer cell then divides, forming an outer, thimble-shaped cell and an inner cell which is somewhat spherical. This inner cell will produce all the sperms. The thimble-shaped cell divides in a very peculiar way, forming a circular *cover cell* and a *ring cell* shaped like a napkin ring. There are only 3 cells in the wall of this antheridium, the basal cell, the ring cell, and the

cover cell. The inner cell divides, forming usually 32 cells, each of which produces one sperm (Fig. 250*D*).

When the antheridium is mature, the cover cell is pushed off and the sperms come out, swimming vigorously by means of their many cilia. If a gametophyte with mature antheridia be placed in a drop of water on a slide, it is instructive to watch the antheridia break open and see the sperms swim.

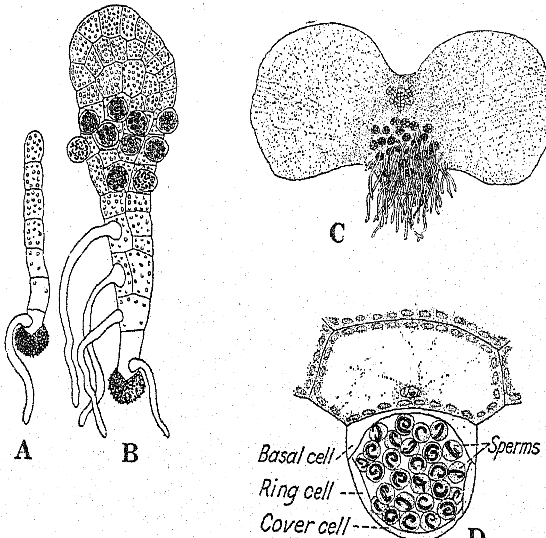


FIG. 250.—Gametophytes (prothallia) of ferns. *A*, *B*, *C*, *Osmunda cinnamomea; D*, *Pteris longifolia*. *A*, filamentous stage, × 90; *B*, later stage, with rhizoids and antheridia, × 90; *C*, still later, with archegonia near the notch, and antheridia below, × 17; *D*, section of an antheridium containing numerous curved sperms, × 400.

The archegonia nearly always begin to develop a week or even a month later than the antheridia, but they are almost always on the same gametophyte. Since new cells keep forming at the notch of the heart-shaped gametophyte, the archegonia are near the notch and the antheridia are farther back (Fig. 250*C*). Sometimes gametophytes live a year or more. In such cases they keep dying off behind, so that all of the part which bore antheridia decays and disappears, leaving only the part bearing archegonia. Careless observers, looking only at very young or very old

gametophytes, might conclued that antheridia and archegonia are borne on different gametophytes.

A mature archegonium has an *egg*, a *ventral canal cell*, and a *neck canal* cell with two nuclei in it. This central row of cells is surrounded by a neck and by some cells of the gametophyte. Such an archegonium and stages leading up to it are shown in Fig. 251.

Soon after the archegonium has reached the stage shown in Fig. 251, the ventral canal cell and neck canal cell become mucilaginous, swelling until they break open the neck of the

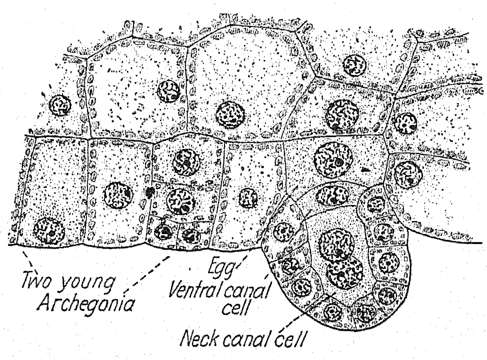


FIG. 251.—Section of part of a gametophyte (prothallium) of *Osmunda* showing a mature archegonium and two younger ones, × 293.

archegonium. In this watery mucilaginous mass the sperms swim down to the egg, and one of them enters, its nucleus uniting with the nucleus of the egg, which thus becomes the first cell of the sporophyte generation.

The Embryo and Sporeling.—The fertilized egg immediately begins to divide and soon the regions which are to form the root, stem, leaf, and foot can be recognized. During these early stages the young plant is called an *embryo;* but as soon as one can see, with the naked eye, a stem, leaf, and root, the young plant is called a *sporeling.* In Fig. 252 the term, embryo, may be applied to the stage shown in *A*, while *B* shows a sporeling still attached to the gametophyte.

The gametophyte soon dies and the young sporophyte, with its root in the soil and a green leaf in the air, is an independent plant which, in time, will produce spores.

Thus, the gametophyte produces the sporophyte, and the sporophyte produces the gametophyte. The two generations alternate. This is an easily observed illustration of alternation of generations.

In the Liverworts and Mosses the sporophyte, throughout its entire lifetime, is parasitic upon the gametophyte; in the Lycopods, Horsetails, and Ferns the sporophyte is parasitic

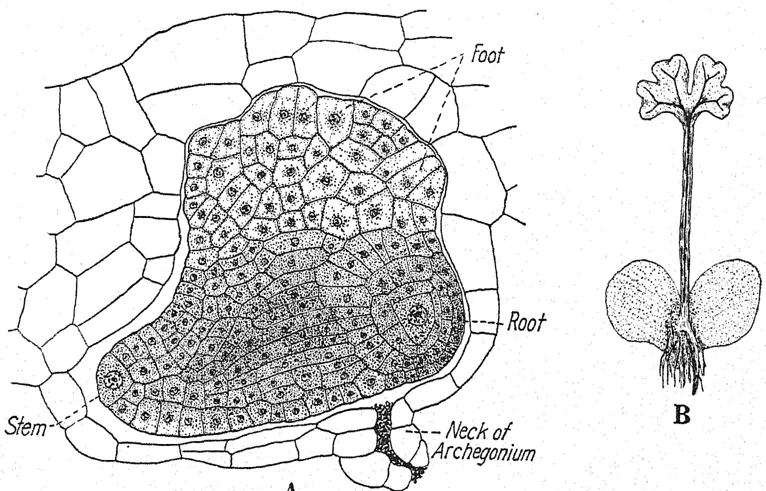


FIG. 252.—*A*, section of a gametophyte (prothallium) of *Pteris*, with a young embryo, × 260; *B*, gametophyte (prothallium) of *Pteris* with sporeling, × 5.

upon the gametophyte for a little while but soon becomes independent; in plants above the Ferns the gametophyte is very small and is parasitic inside the sporophyte.

THE WATER FERNS

The Water Ferns are seldom studied by beginners, but they deserve a place because they are so remarkable. There are only four of them, two growing in the water or in wet places but always rooted in the soil, and two floating on the surface of the water. The four do not look like each other and none of them look like Ferns. All are heterosporous.

Marsilia.—The Water Fern most widely distributed and most easily obtained is *Marsilia*. It is found from Dakota to Texas

and from the Atlantic to the Pacific. It has a rhizome in the soil and leaves which look like a four-leaf clover (Fig. 253). If the plant is growing in the water the leaflets float upon the surface; growing on the bank the leaves stand erect.

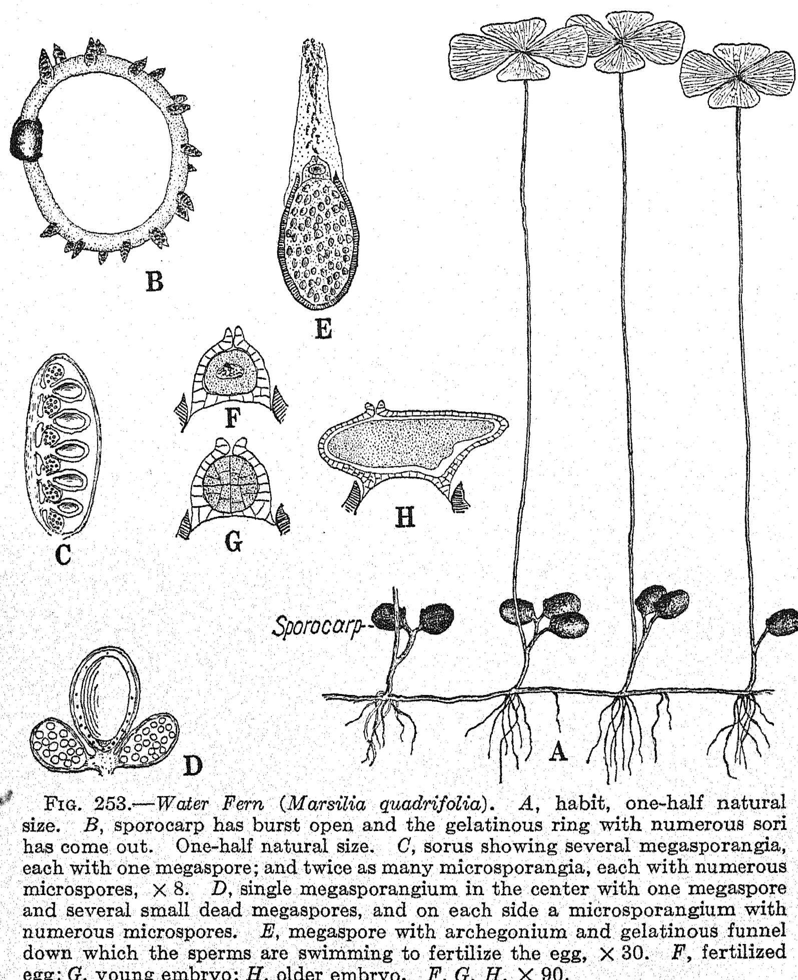


FIG. 253.—*Water Fern* (*Marsilia quadrifolia*). *A*, habit, one-half natural size. *B*, sporocarp has burst open and the gelatinous ring with numerous sori has come out. One-half natural size. *C*, sorus showing several megasporangia, each with one megaspore; and twice as many microsporangia, each with numerous microspores, × 8. *D*, single megasporangium in the center with one megaspore and several small dead megaspores, and on each side a microsporangium with numerous microspores. *E*, megaspore with archegonium and gelatinous funnel down which the sperms are swimming to fertilize the egg, × 30. *F*, fertilized egg; *G*, young embryo; *H*, older embryo. *F*, *G*, *H*, × 90.

The sporangia are borne inside hard nutlike structures called *sporocarps*. A sporocarp contains many sori and each sorus contains several microsporangia and megasporangia.

The most remarkable thing about *Marsilia* is the germination of its spores. Dry sporocarps which have been laid away for 50 years may begin to show signs of life within 5 minutes, if cut along one side and placed in water. A gelatinous ring, bearing numerous sori, comes out from the sporocarp (Fig. 253); the microspores and megaspores contained in the sporangia at once begin to germinate; from each megaspore there develops a small gametophyte bearing one archegonium with an egg, a ventral canal cell, and a neck canal cell; while each microspore produces a small gametophyte, entirely contained within the spore. The gametophyte produces two antheridia, each with 16 sperms. This whole process, from the time the sporocarp is put into the water until the eggs and sperms are mature and fertilization takes place, may not be more than 10 or 12 hours. It is seldom more than 24 hours before the sperms can be seen swimming in the mucilaginous funnel over the neck of the archegonium. In 3 or 4 days little green plants can be seen easily without a lens.

CHAPTER XVI

SPERMATOPHYTES. SEED PLANTS

The most familiar of all plants are the Seed Plants. They include most of the herbs and nearly all of the shrubs and trees. All have seeds, and no other plants have seeds. They are often called the Flowering Plants.

There are two great divisions of Seed Plants, Gymnosperms and Angiosperms. The Gymnosperms have their seeds borne on open sporophylls. The word, Gymnosperm, means *naked seed.* The Angiosperms have their seeds enclosed in an ovary, which is usually made up of sporophylls, united so as to form one or more cavities, or chambers. The *Ang-* means a room or chamber, and *-sperm,* in this case, means seed. In Gymnosperms the seeds are naked; in Angiosperms, they are enclosed in an ovary.

The sporophyte is the conspicuous generation; the gametophyte is small and parasitic and is enclosed within the sporophyte.

The principal organs of a Seed Plant are leaf, stem, root, flower, fruit seed, the male gametophyte, and the female gametophyte.

Nearly all of Part I was devoted to such features of these organs as can be studied without a microscope. In the present study the emphasis will be upon life histories and development, both of which demand some study of microscopic structures.

GYMNOSPERMS

Nearly all the Gymnosperms are trees; there are a few shrubs, but no herbs. All can be placed in two great groups, the Cycadophytes and the Coniferophytes (Fig. 254).

The Cycadophytes have large Fernlike leaves in a crown at the tip of a straight unbranched stem. They look like Tree Ferns or Palms. The stem, in cross-section, shows a large pith, scanty wood, and a large cortex.

The Coniferophytes have a much branched stem, with small leaves which are usually so rigid that they are called needles,

The stem, in cross-section, shows a small pith, large zone of wood, and a small cortex.

Cycadophytes.—Some members of this group are popular decorative plants, but most of them became extinct millions of years ago. It is an interesting fact that an almost unbroken family line can be traced back from the living members to those known only from fragments preserved in the rocks.

Fossil Cycads.—In far away geological times, possibly 100,000,000 years ago, in the period which is called the Coal or Carboniferous Age, the lower members of this group were very abundant. They looked so much like the Ferns, which were their ancestors, that they were mistaken for Ferns and botanists often called the Coal Age the Age of Ferns. Most of the impressions of Fernlike leaves which one finds in coal mines belong to these early Seed Plants (Fig. 255).

Later, when those gigantic reptiles were wandering around, whose skeletons nearly a hundred feet long excite our imagination, smaller Seed Plants, the Fossil Cycads, inheriting a Fernlike appearance from their extinct ancestors, were so abundant that their period was called the Age of Cycads.

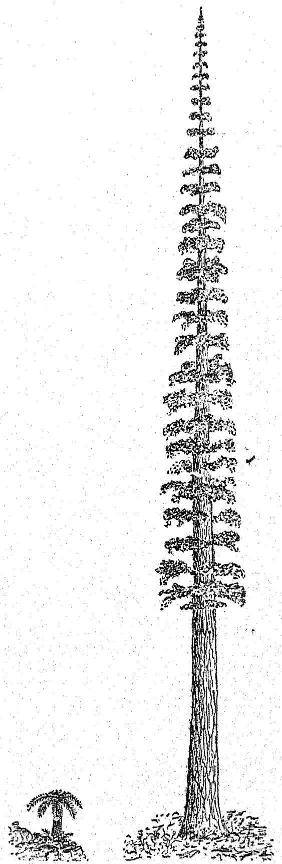


FIG. 254.—Sketch showing the comparative size of average plants in the Cycadophyte and Coniferophyte groups of Gymnosperms.

Their microsporophylls—male sporophylls—looked like the foliage leaves, only smaller, and they bore the microsporangia on their margins. The megasporophylls—female sporophylls—were crowded together into a cone at the center of the crown of microsporophylls. A glass model of this

FIG. 255.—Portion of fern-like leaf of *Pecopteris*, from Mazon Creek, Ill. (*After Noé*).

flower, with its microsporophylls outside, the cone of megasporophylls inside, and the hairy bud scales which protected the flower while it was in the bud, may be seen in the Field Museum of Natural History in Chicago (Fig. 256).

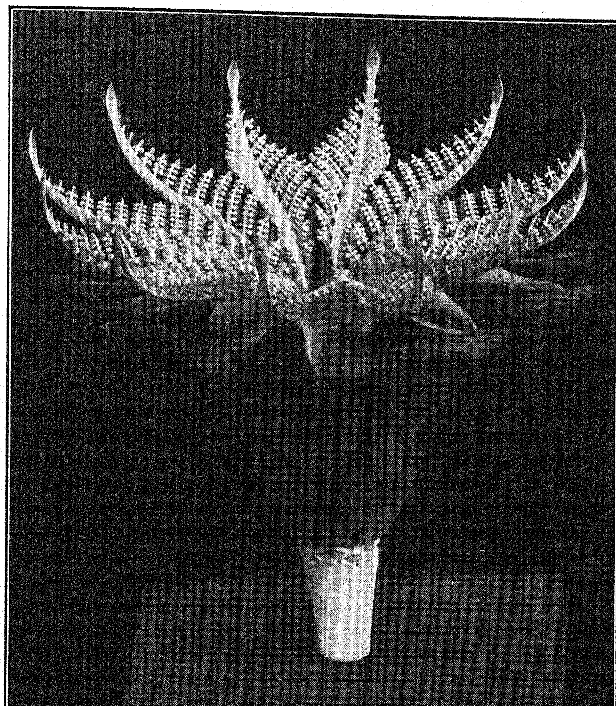


FIG. 256.—*Cycadeoidea ingens.* Leaf-like microsporophylls on the outside and small ovulate cone in the center. (*From a glass model in the Field Museum at Chicago. Model made by Sella, with the advice and criticism of Wieland.*)

The living Cycads, like the fossil Cycads, came from the Fernlike Seed Plants of the Coal Age, and have retained so many ancient characters that they may be called living fossils. They are seldom studied by beginning classes, but they are not difficult to understand, and they should be interesting to anyone, just as the Pyramids of Egypt and King Tut's tomb are interesting to one who wants to know something of ancient history.

The Living Cycads.—A million years ago, before the Great Ice Age, when the climate of Greenland and Alaska was as warm

as that of southern Florida or southern California, the living Cycads grew all over the world; but now, they are confined to tropical and subtropical regions, and even there they occur in scattered patches.

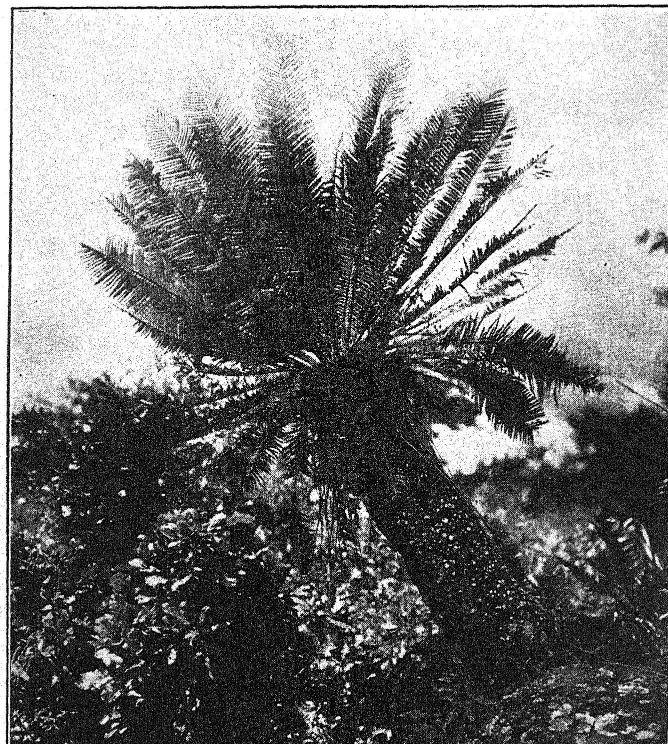


FIG. 257.—*Dioon edule* at Chavarrillo, Mexico.

Only one of them, *Zamia*, called the Coontie, is native in the United States, and it is found only in Florida. Most of the Cycads however, can be set out in our gulf states and Pacific states and will grow as if they were native. One of them, *Cycas*, called the Sago Palm, is a familiar decorative plant on lawns in our gulf states and on the California Coast; and almost every greenhouse will have specimens of it; for its rigid dark green leaves are in great demand on Palm Sunday and for making funeral wreaths.

A typical view of a Cycad is shown in Fig. 257. In the field nearly all the older plants have this leaning habit, and most of them die on account of it. As a plant reaches a height of four or five feet, the big crown of leaves offers great resistance and the wind either blows the plant down or makes it lean. The heavy wood and big crown make the plant top heavy, so that any further growth makes it lean still more and, after a hundred years or so, it falls down. But where it is strained or broken at the base, a bud appears and develops into a new plant, as shown in Fig. 257.

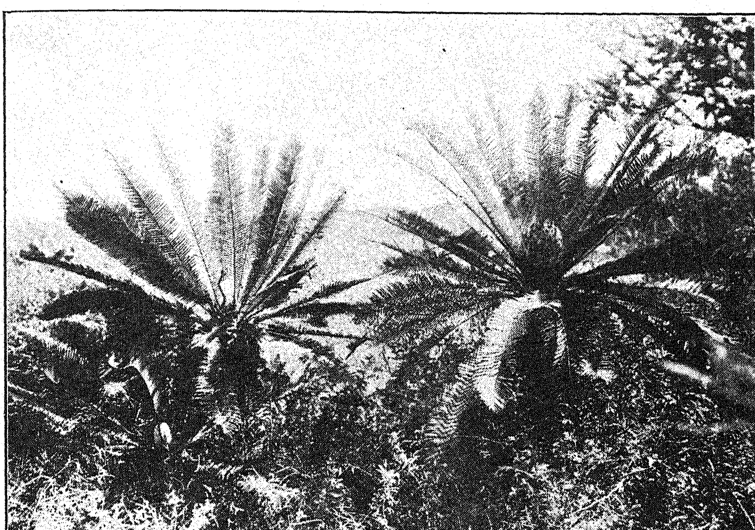


FIG. 258.—*Dioon edule* at Chavarrillo, Mexico. Male plant at the left and female at the right. The plants, to the tops of the leaves, are about 7 feet high.

Most Cycads grow very slowly. The one shown in Fig. 257 is about 5 feet high and about 1,000 years old. The age is easily estimated. *Dioon edule* produces about 20 leaves in a crown and produces a new crown every other year, an average of 10 leaves a year. The leaf bases remain on the plant and can be counted. If there are 10,000 leaf bases and the plant forms an average of 10 leaves a year, the plant is 1,000 years old.

The Cycads are dioecious, with male cones on one plant and female cones on another (Fig. 258).

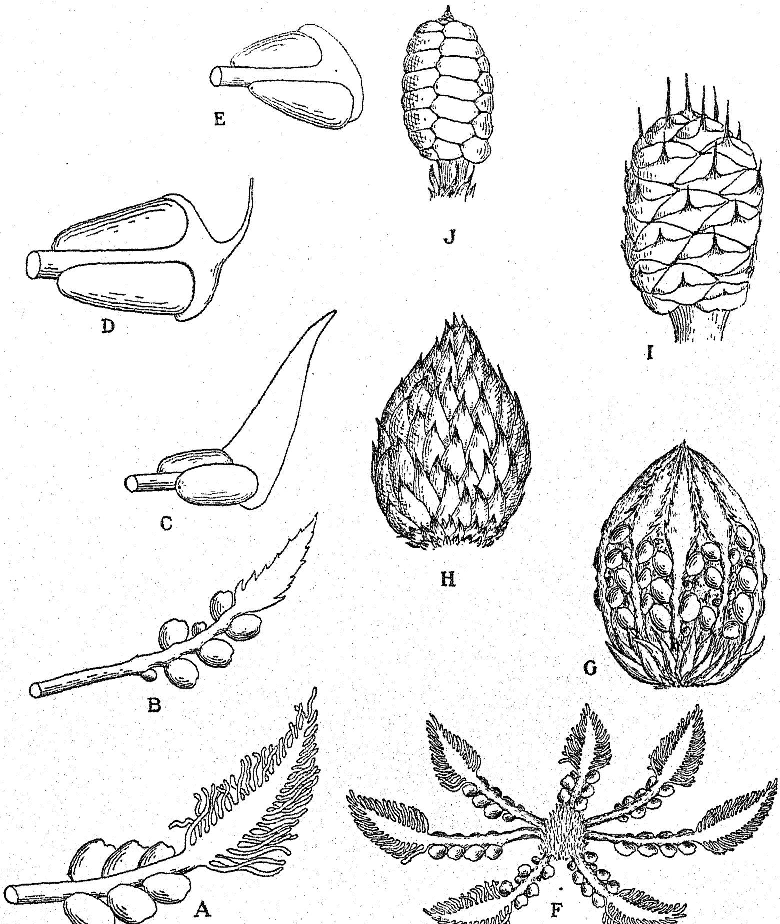


FIG. 259.—Megasporophylls and cones of cycads. *A*, *Cycas revoluta*, with leaf-like megasporophyll, and *F*, the arrangement of megasporophylls, not crowded into a cone; *B*, *Cycas media*, leaflets of megasporophyll much reduced, and *G*, grouping of megasporophylls so that, in early stages, the structure looks like a cone; *C*, *Dioon edule*, leaflet character entirely lost, and *H*, the grouping into a rather loose cone; *D*, *Macrozamia miquelii*, the leaf character nearly lost, the midrib remaining as a spine, and *I*, a well organized cone; *E*, *Zamia floridana*, even the midrib character has been lost, and *J*, the megasporophylls are grouped into a very compact cone.

Some general tendencies in development are better illustrated in the Cycads than in any other group. The megasporophylls, in the lower members of the group, are much like the foliage leaves only smaller; and in higher members they become less and less leaflike, until most of the resemblance to a foliage leaf is lost (Fig. 259).

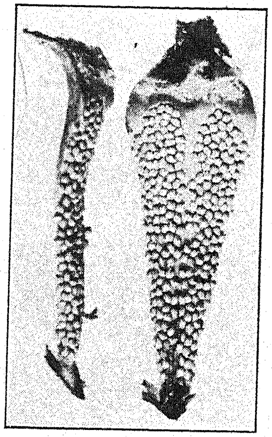


FIG. 260.—*Dioon edule.* Microsporophyll showing side and back views. Natural size.

In the ordinary Fern the sporangia are borne in sori on the underside of the leaf. In the Cycads the microsporangia are borne on the underside of a much modified leaf, the microsporophyll, and they are in sori, with five, four, three, or two microsporangia in a sorus and, occasionally, only one (Fig. 260). In the lower members of the Cycads there are hundreds of microspoangia on a sporophyll; but in the higher members there are less than a hundred.

The details of pollination, fertilization, and early development of the embryo are difficult to follow in the material, and material

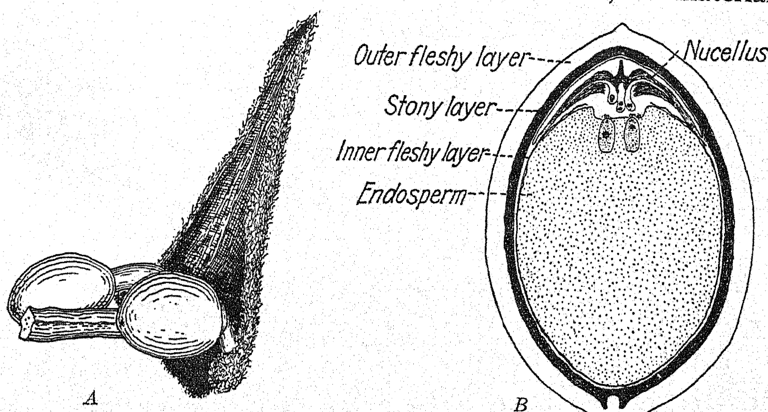


FIG. 261.—*Dioon edule.* *A*, megasporophyll with two ovules (megasporangia) one-half natural size; *B*, longitudinal section of an ovule, $\times$ 2.

is hard to get, but some of the most important features can be understood from a study of Figs. 261 to 263. If these figures are

studied carefully, there should not be much trouble with life histories in the rest of the Seed Plants.

The plant at the right in Fig. 258 shows a female cone made up of megasporophylls. One of these megasporophylls, with its

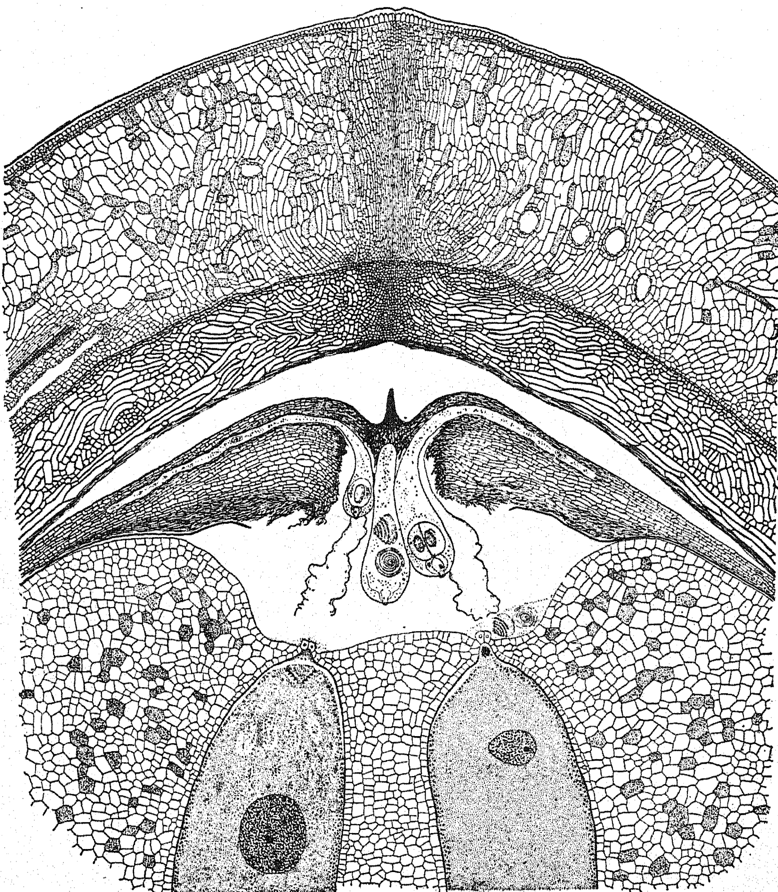


FIG. 262.—*Dioon edule.* Upper part of a section like that in Fig. 261*B*. × 74.

two seeds, is shown in Fig. 261*A*; a longitudinal section of one of the seeds is shown in *B*; and Fig. 262 shows a highly magnified view of the upper part of Fig. 261*B*. At the top in Fig. 262 is the seed coat, consisting of the outer fleshy layer of the integu-

ment *f*, below which is the stony layer *s*. Below that is the megasporangium (nucellus), containing five pollen tubes, two of which have shed their sperms. The other three pollen tubes still retain their contents, the middle one having two sperms with spiral coils. If the magnification were higher, these coils would show an immense number of cilia which enable the sperm to swim. Two sperms, which have just been discharged, can be seen near the tip of the empty pollen tube at the right.

Just below the pollen tubes is the top of the female gametophyte (megagametophyte), containing two eggs, which are shaded in the drawing. In the egg at the left a sperm may be seen at the top, and farther down is the nucleus of the egg, still more deeply shaded. The sperm will move down and its nucleus will unite with that of the egg, thus fertilizing it. The fertilized egg is the first cell of the new sporophyte. Its nucleus divides and divisions continue until there are hundreds of nuclei not separated by walls. Then walls appear at the lower part and the cells become differentiated into a root, stem, cotyledons, and leaves (Fig. 263).

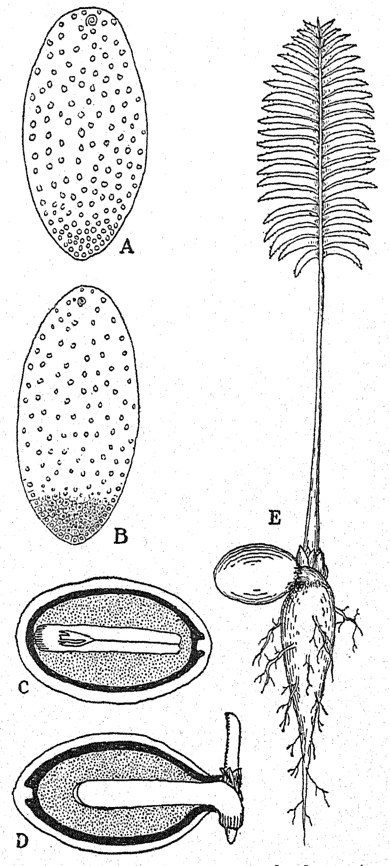


Fig. 263.—*Dioon edule*. *A*, young embryo with numerous nuclei not separated by walls, × 15; *B*, later stage with walls at the bottom, × 15; *C*, ripe seed showing embryo embedded in endosperm, natural size; *D*, embryo with root pointing down and first leaf pointing up, coty ledons remaining in the seed, natural size; *E*, seedling with first leaf. The seed remains attached, often for a year or more. One-half natural size.

Without any resting period, the seed germinates and the young plant grows to maturity, and produces crowns of leaves, and, once in a while, a cone; then, after a thousand years or so, it begins to lean and, finally, falls down and dies.

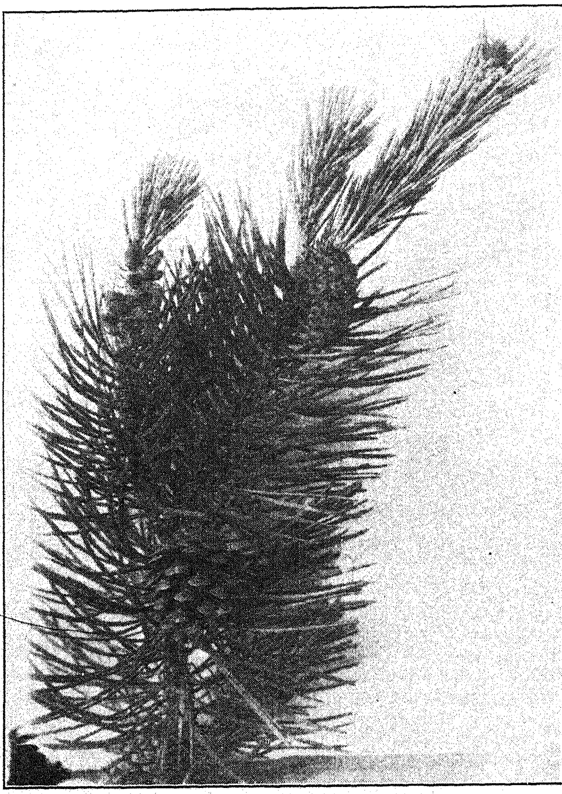


FIG. 264.—*Pinus contorta.* Group of male cones at the left, at the time of shedding of pollen. At the tip, a young female cone at the time of pollination. Farther down, a female cone a year older. Still farther down, a female cone two years older than the one at the tip. (*Photographed at the Puget Sound Biological Station, June 15, 1929.*)

If this life history is studied thoroughly, it will be a great help in understanding the life histories of all the higher plants.

Coniferophytes.—This line, like the Cycadophytes, can trace its ancestry back a hundred million years. Even at that distant time, as far back as any fragments have been preserved in the

rocks, the Coniferophytes had the small simple leaves and branched stems which contrast so sharply with the large pinnate leaves and unbranched stems of the Cycadophytes.

The Leaves.—In the living Coniferophytes the rigid needle type of leaf, like the Pine needle, is almost universal (Fig. 264).

Nearly all the Coniferophytes are evergreen, because the rigid leaf is not killed by hard winters or other unfavorable conditions. It lives three, four, or five years, or even longer. New leaves are formed every year, and many leaves fall every year, so that the forest floor is carpeted with fallen needles; but there are always living leaves which keep the tree green.

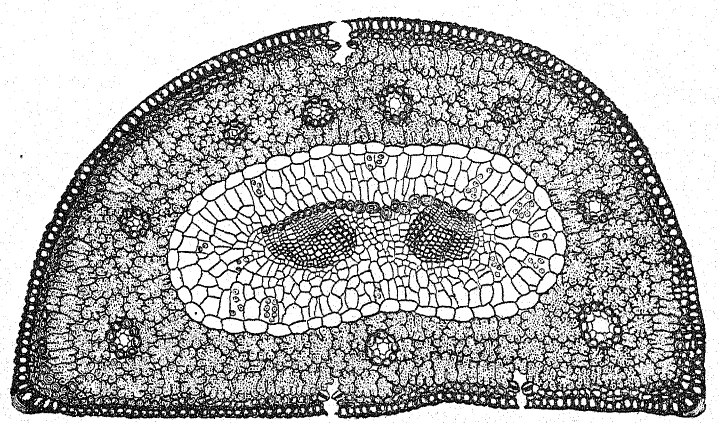


FIG. 265.—*Pinus laricio.* Cross-section of leaf. × 65.

The structure of a Pine needle, as it appears in cross-section, shows how perfectly it is suited to endure hard conditions (Fig. 265). The cells of the epidermis have thick walls and their outer surface is covered with a varnish-like substance which keeps them from getting wet. The stomata are sunken and have very small openings, which are usually closed. The walls of the cells next below the epidermis are thick and corky, still further protecting the cells inside. There are two conducting bundles, which do not branch, even when the needles reach a foot or more in length.

Snow, which gives the evergreens such an artistic appearance in winter, is a great protection against cold. The smoke and dirt of large cities is fatal to trees and shrubs whose leaves must serve more than one year, for the stomata become clogged the

first year and the leaf is likely to fall the next year. So, the leaves become fewer each year, and the tree soon dies. Evergreen trees are rapidly disappearing from our larger cities, largely on account of the smoke nuisance. Trees and shrubs which shed their leaves every year are also affected, but the result is that the leaves fall a little earlier in the Autumn. The next spring they bring out new leaves.

In a few plants of this great line the leaves fall every year. Our only examples are the Larch, the Swamp Cypress, and the much cultivated Maiden Hair Tree.

The Stem.—The tall straight stem, with comparatively small branches, makes this group so valuable for timber. Some of our finest trees are shown in Figs. 21 to 26.

Some are smaller, like the Yew and Juniper. The fragrant wood of one of the Junipers, often called the Red Cedar, is used in making lead pencils and hope chests and in lining wardrobes.

In any log, as it is sawed into boards, the grain of the boards near the bark is different from that of boards near the pith. The difference is due, largely, to the annual rings. In each ring the wood formed late in the season is harder than that formed in the spring. The age of a board can often be determined by looking at the grain, just as the age of a tree can be found by counting the rings. In a cross-section of a young stem of the Douglas Fir, shown in Fig. 43, the difference between the hard autumn wood and the softer spring wood is very striking and makes the rings easy to count. It also makes the grain of the board as striking as in Oak, where the autumn wood is much harder than the spring wood (Fig. 44).

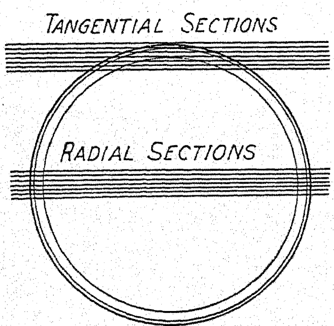


FIG. 266.—Diagram showing the direction of tangential and radial sections.

The microscopic structure is just as characteristic as the grain. To understand the structure of a stem, it is necessary to study a cross-section and two longitudinal sections, one of which must be tangential and the other radial (Fig. 266). The diagram shows how the sections should be cut and it also shows that if one

began cutting longitudinal tangential sections and kept on cutting, when he reached the pith the sections would be longitudinal radial. A radial section is one cut parallel with the pith ray.

The principal features of a young Gymnosperm twig, seen best in cross-section, are the wood, cambium, phloem, pith rays, cortex, and epidermis (Fig. 267).

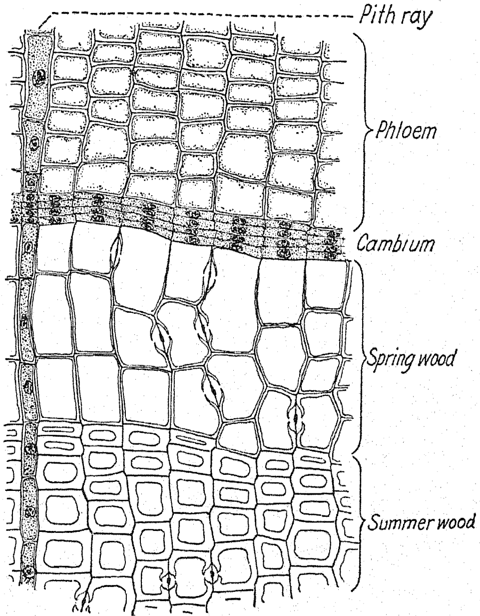


FIG. 267.—*Pinus laricio* (*Austrian Pine*). Cross-section of part of twig, × 300.

In the spring when growth is vigorous, large cells are formed; but as growth slows down in summer, the cells become much smaller, and, where it is very cold, no cells at all are formed in the autumn and winter. The next spring large cells are formed again, so that the smallest cells come next to the largest ones and make the annual ring.

The thick-walled cells of the wood are dead, but the outer ones, forming a zone of lighter colored wood, called the *sap wood*, still duct materials. The cambium is alive and keeps forming new wood on the inside and new phloem on the outside as long as the plant lives.

In nearly all of the Coniferophyte line, there is an abundant formation of resin, some of which is valuable. Canada balsam comes from the Balsam Fir; turpentine from the Yellow Pine; Venice turpentine, from the Larch; and Dammar varnish from the Kauri. The resin is formed in the wood or cortex or in the leaves (Fig. 265); but it may flow out and collect in considerable masses outside the bark. For turpentine, a cut is made into the tree and the turpentine flowing from the wound is caught in a cup fastened to the tree.

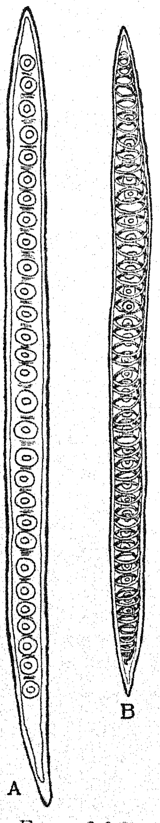


FIG. 268.—Tracheids with bordered pits. *A*, *Pinus strobus*; *B*, *Taxus brevifolia*. × 150.

Every plant is made up of cells. In the Gymnosperms nearly all the wood is made up of thick-walled elongated cells pointed at both ends (Fig. 268). These cells, called *tracheids*, have numerous circular pits with a pore at the top. These *bordered pits* are found in all Gymnosperms. In some, like the Yew, the tracheids have spiral thickenings in addition to the bordered pits. The spirals act like springs and make Yew bows so popular with archers who can afford them (Fig. 268*B*).

Longitudinal radial and longitudinal tangential sections of Pine wood, as they appear under a low magnification, are shown in Fig. 269; and a tiny cube of White Pine, as it would look when greatly magnified, is shown in Fig. 270.

In the Gymnosperms the protoxylem is next the pith and, consequently, the stem is an endarch siphonostele.

The Root.—A cross-section of an old root looks very much like that of a stem, except that the bark is not so thick or so cracked. The annual rings look like those of the stem, and there are the same tracheids with bordered pits and the pith rays. A young root, however, looks different, for the stele is radial exarch (Fig. 271).

The Flower.—Nearly all the flowers are cones. The name, Coniferophyte, means cone-bearing plant. The Pine cone is a familiar example (Figs. 106, 264). When one thinks of a cone he

has in mind the female cone, which is often called the ovulate cone, because it bears the ovules (megasporangia.)

The male cone is also called the staminate cone because it is made up of stamens, and called the microsporangiate cone because each stamen bears two or more microsporangia. In a Pine the male cone is formed in the summer and autumn, remains covered with bud scales during the winter, and in the spring grows rapidly,

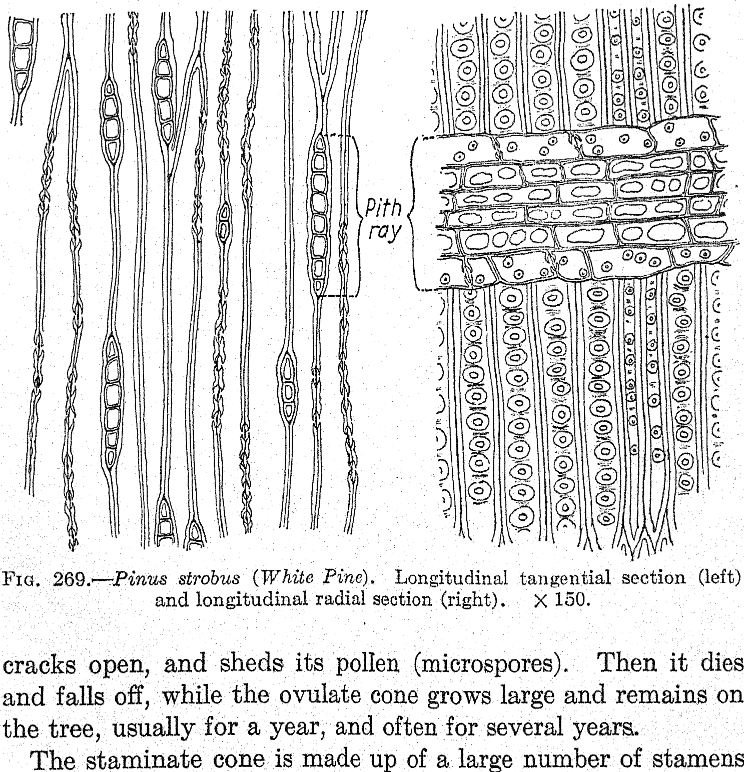


FIG. 269.—*Pinus strobus* (*White Pine*). Longitudinal tangential section (left) and longitudinal radial section (right). × 150.

cracks open, and sheds its pollen (microspores). Then it dies and falls off, while the ovulate cone grows large and remains on the tree, usually for a year, and often for several years.

The staminate cone is made up of a large number of stamens (microsporophylls), each of which bears two microsporangia. Since each microsporangium contains a thousand or more microspores, the number of microspores is very large (Fig. 272).

The microspore is the first cell of the male gametophyte. It begins to germinate and usually forms four cells before it is shed. Two of these cells are very small, but they represent the green prothallium (gametophyte) of the fern and, on that account, are

called prothallial cells. The prothallium of the fern bears many antheridia. This two-celled prothallium bears only one antheridium, which is the rest of the microspore (Fig. 272).

At this stage of development the microspores are shed and are blown in all directions by the wind, and in Pine forests the air is

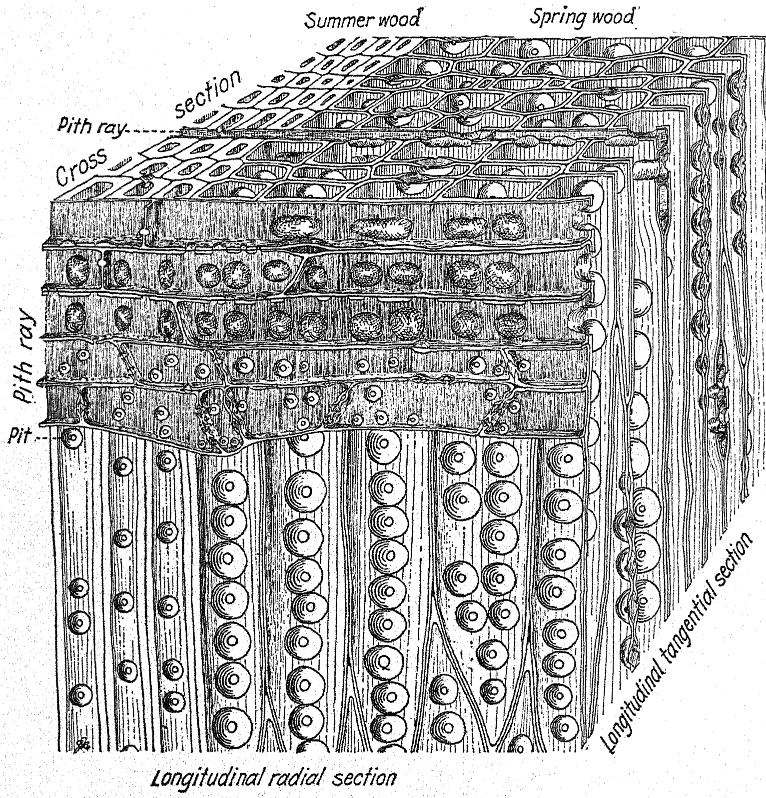


FIG. 270.—*Pinus strobus* (White Pine). A cube, reconstructed from drawings of three sections of the mature wood. × 400.

so full of them that lumbermen talk about "sulphur showers." Of the hundreds of millions of microspores produced by a Pine tree, nearly all fall to the ground and die; but a few reach the megasporangia, where they are caught by a tiny drop of sparkling liquid which oozes out from the tip of each microsporangium at just the time when the microspores are being shed (Fig. 273).

The microspore coat now breaks, and a tube, called the *pollen tube*, grows down through the top of the megasporangium (Fig. 274). Two sperms are formed in the pollen tube. They have no cilia and cannot swim. There are no swimming sperms here or in any higher plants.

When the microspores are being caught in that sparkling drop, the megasporangium contains four megaspores; but one of them soon absorbs the other three and grows large. The nucleus of the

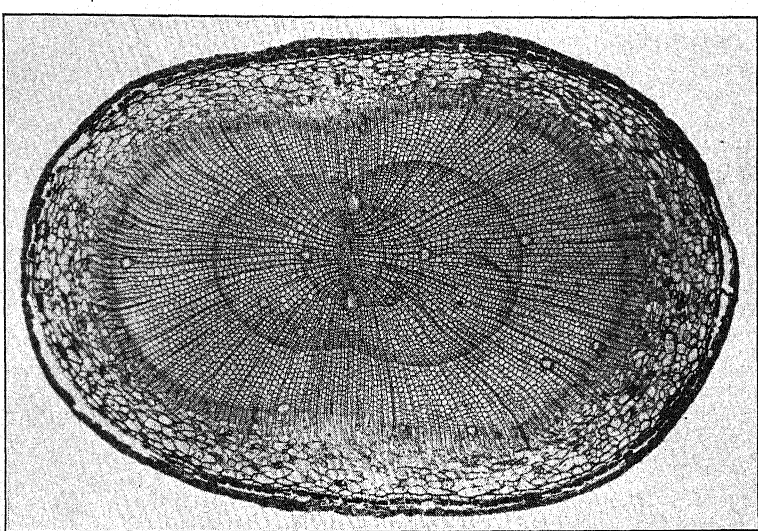


FIG. 271.—*Picea nigra* (Spruce). Cross-section of root. (*Photomicrograph by Sedgwick; from a preparation by R. B. Thomson.*) × 28.

large, growing megaspore divides, the two resulting nuclei divide, and this continues until there are hundreds of nuclei not separated by walls (Figs. 273, 274); but cell walls are soon formed, and the megaspore becomes filled with thousands of cells. This is the female gametophyte, perfectly equivalent to the green, heart-shaped gametophyte (prothallium) of a Fern. In the Fern the spore was shed from the sporangium and, when it germinated, the spore coat cracked and the gametophyte broke out and became green. In the Pine the megaspore always remains inside the megasporangium. It is never shed and it is so protected from the light that it does not get green. The female gametophyte

stays inside the megaspore, as can be seen in any good section, for the megaspore coat stains deeply (Fig. 274).

When the female gametophyte has reached nearly its full size, a few archegonia appear at the top end of it. The neck of the archegonium is short, consisting of a few cells, and there are no

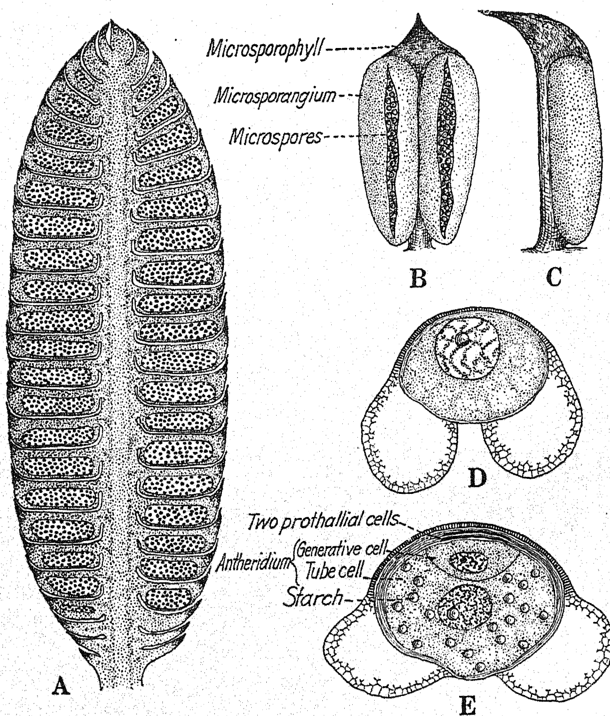


FIG. 272.—*Pinus laricio* (Austrian Pine). *A*, longitudinal section of male (microsporangiate) cone, × 5; *B* and *C*, back and side views of microsporophyll, × 14; *D*, microspore, × 600; *E*, pollen grain, × 600.

neck canal cells; but there is a ventral canal cell and an egg (Fig. 274).

Fertilization.—The egg is now ready for fertilization. The end of the pollen tube breaks and its contents enter the egg. One of the sperm nuclei moves down and unites with the nucleus of the egg, thus fertilizing it. The fertilized egg is the first cell of a new plant, the sporophyte generation, which may grow until it becomes a big tree (Fig. 275).

The Embryo and Seedling.—While the sporophyte is very young and still enclosed in the seed, it is called an *embryo;* after it breaks out and becomes green, it is called a seedling (Figs. 276, 277).

The early development of the embryo from the fertilized egg is as regular as a geometric figure. The nucleus of the fertilized egg divides and the two resulting nuclei divide, without any cell walls coming in between the four nuclei. These four nuclei

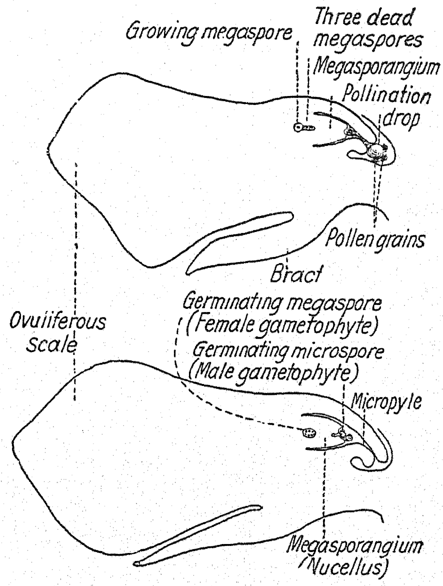


FIG. 273.—*Pinus laricio* (Austrian Pine). Megasporophylls. × 50. *A*, at time of pollination, showing pollination drop with three pollen grains sticking to it; also one megaspore enlarging and three disorganizing; *B*, later stage, with pollen tube starting and the megaspore germinating.

sink to the bottom of the egg and all four divide at once, so that there are eight nuclei, and this time walls are formed between the nuclei. Two more divisions take place so as to make four tiers of cells, with four cells in each tier (Fig. 275). The young embryo then breaks through the bottom of the egg and splits into four filaments with four cells in each filament. The lowest cell in each filament starts to develop independently, while the cell just behind it elongates and pushes the end cell down into the rich starchy endosperm (Fig. 276). While all four of the

end cells start to develop, one soon gets a little deeper into the endosperm and uses up the surrounding food. The other three soon die (Fig. 276).

The Pine embryo has several cotyledons, and, when the seed germinates, they stay inside for a little while and are carried up into the air by the elongating seedling.

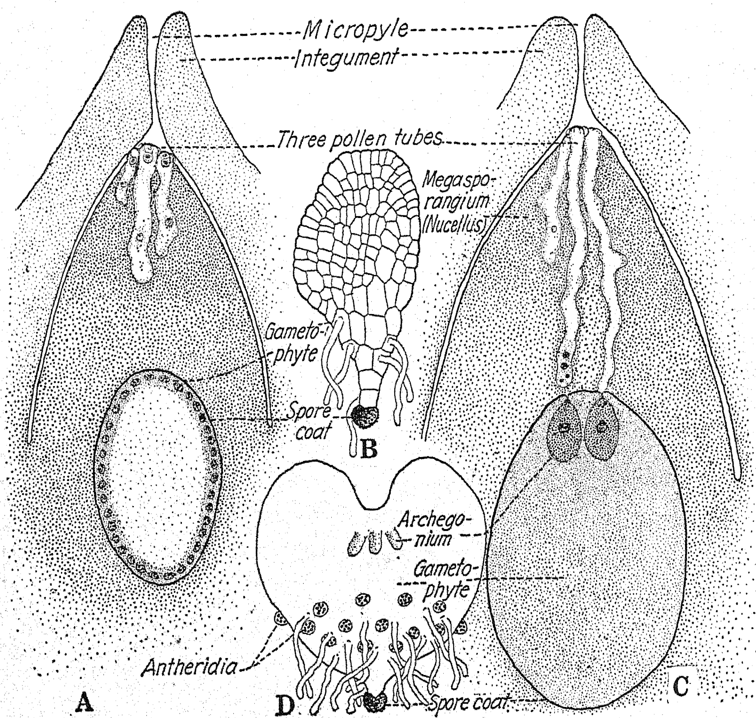


Fig. 274.—*Pinus laricio* (Austrian Pine). *A*, three pollen tubes growing down into the megasporangium (nucellus). The germinating megaspore contains many free nuclei in a thin layer next to the megaspore coat. *C*, fertilization stage. Both × 50. The stages in the female gametophyte correspond to the stages in fern gametophyte indicated in *B* and *D*.

Just above the cotyledons, leaves soon begin to develop. The first leaves are simple, like those of the Spruce, Fir, and Juniper; but even before the seedling is a year old, short branches, called *spurs*, begin to appear in the axils of leaves, and each spur bears two, three, or five needle leaves (Fig. 277). The various Pines

are characterized by the number of leaves on a spur. The Scotch Pine has two leaves on a spur, the Yellow Pine has three, and the White Pine has five.

In many Gymnosperms the first leaves of the seedling are needle-like, but the later leaves are flattened, as in the Arbor Vitae, the Eastern Red Cedar, and the Western Red Cedar. In the Western Red Cedar the branches look like Fern leaves,

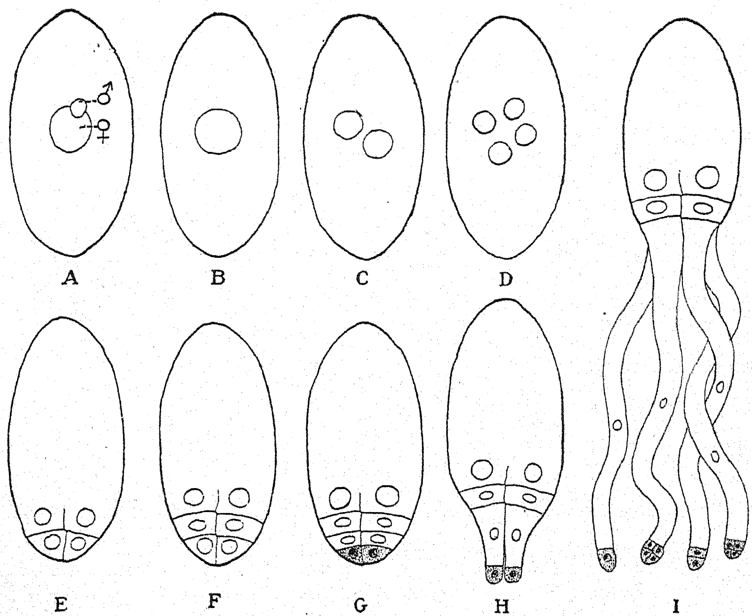


FIG. 275.—*Pinus laricio* (Austrian Pine). A series of stages from fertilization of the egg (*A*), up to the stage in which the four embryos have split apart. × 50.

but it is easily seen that the real leaves are very small and flattened.

In the Maiden Hair Tree, which is becoming so popular in cultivation, the leaves are very beautiful and look more like leaves of Dicotyls. The seeds are not in cones but are borne on long stalks and look like plums.

There are others, like the Yew, which do not have their seeds in cones. These are sometimes called *Conifers without cones.*

Economic Value.—The Gymnosperms furnish a great part of the world's supply of lumber. In some the wood is white and

soft; in some it is hard and yellow; in some it is red and soft; while in others it is red and hard.

The Gymnosperms of the Southern Hemisphere are very different from those of the Northern, only a couple of Cycads and a couple of Conifers being common to both hemispheres. There are immense forests of Gymnosperms in the Southern Hemisphere which have hardly been touched by lumbermen;

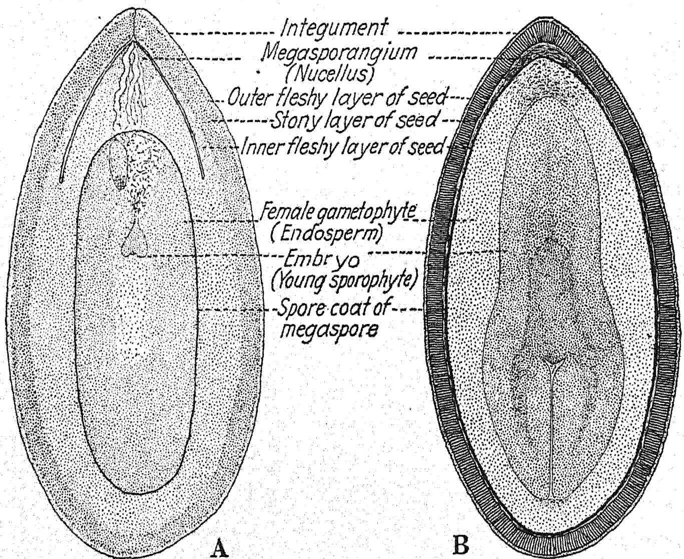


FIG. 276.—*Pinus laricio* (Austrian Pine). Longitudinal sections of young (*A*) and mature (*B*) seeds. × 12.

while in the Northern Hemisphere, White Pine has been cut until it has become an expensive luxury. The big Redwood of California was in such danger that a society was formed to *save the Redwoods.*

Gymnosperms, especially Pines, are now being planted in great numbers by our Department of Agriculture, and scientific forestry is likely to do much to preserve and increase this important group of plants.

The Gymnosperms have long been popular as decorative plants. Trees 50 or 100 years old surround farmhouses throughout the country. The Spruce is most abundant, but there are also

Pines, especially the Scotch and Austrian Pine. The Juniper, or Red Cedar, is also in favor; and in cemeteries the Cypress and Arbor Vitae are everywhere.

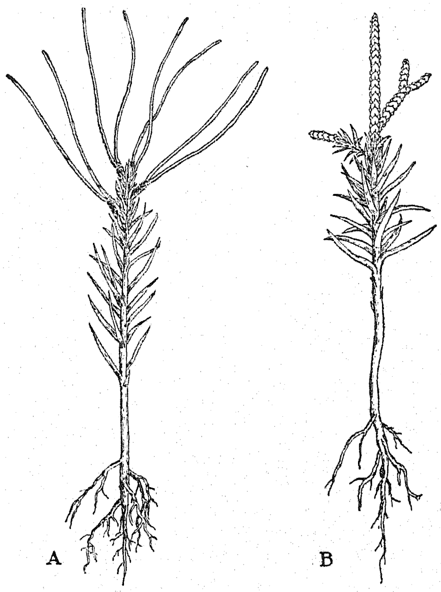


FIG. 277.—Seedlings of *Pinus laricio* (Austrian Pine) *A*, and *Thuja plicata* (Western Red Cedar) *B*. Both have needle leaves at first, but the Pine soon produces long needle leaves on short "spur" branches, while the Cedar produces the much flattened leaves. Both one-half natural size.

Just now, small Gymnosperms are being planted on city lawns. Small varieties of Arbor Vitae and Juniper are everywhere, but Spruce and Pine still hold their place.

CHAPTER XVII

SPERMATOPHYTES. SEED PLANTS (*Continued*)

ANGIOSPERMS

People who know nothing of botany think of it as merely the study of flowers; but it is as important as zoology, chemistry, physics, or geology, because the food supply of the world depends, primarily, upon plants. The animal kingdom would become extinct within a month, if there were no plants.

Most of the plants which furnish the food supply are Angiosperms. They are the only plants in which there are flowers with a calyx and a corolla; many people think of them as the Flowering Plants; but many Angiosperms, like the Willow and Poplar, have neither calyx nor corolla; and none of the Gymnosperms, which are also Flowering Plants, have any calyx or corolla. No one has ever yet made a definition of a flower which would include all the Seed Plants and exclude all the Lycopods and Ferns.

The Seed Plants (Spermatophytes) comprise the Gymnosperms and Angiosperms. In the Angiosperms the seeds are inclosed in an ovary; in the Gymnosperms the seeds are not inclosed in an ovary.

The cells of Angiosperms are more favorable for study than those of any other group, and so, before describing Angiosperms, this is a good place to stop for a study of the cell.

The Cell.—The cell is the unit of plant structure. Every plant is made up of a single cell or of several cells joined together. The largest Big Tree and the largest elephant are made up of millions of cells.

When first formed, the cells of the Big Tree are much alike; but some become long and slender, some remain soft, and some get hard; some manufacture food, while others conduct it from place to place, and still others use it or store it. Some cells serve for protection and others for reproduction. There is an extreme division of labor among the cells of a large plant, in a one-

celled plant, like *Chlamydomonas*, all functions are performed by the one cell.

In the animal there is the same division of labor. Some cells digest the food, some conduct it from place to place; there are nerve cells, muscle cells, and blood cells. The bones and even the enamel of the teeth are made up of cells. So, every living thing is made up of cells.

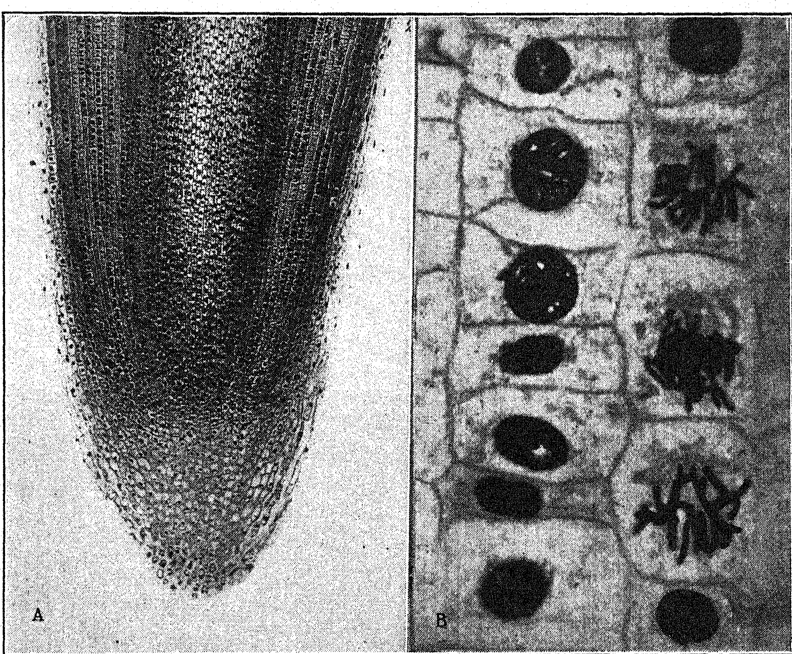


FIG. 278.—*A*, longitudinal section of root tip of Spider Lily (*Tradescantia virginica*) showing hundreds of cells, × 70; *B*, a dozen cells, three of them dividing, × 784.

The cells of a tree are, at first, more or less cubical; what they become later depends, principally, upon their position.

Nothing is better than a root tip for introducing a study of the cell; even zoologists are likely to use it instead of their own material.

The tip of a root of a Spider Lily, an Onion, a Bean, or *Trillium* is very good, because the cells are rather large. Much can be seen in a thin section, cut with a safety razor blade,

mounted in a drop of water, and covered with a thin cover glass; but it is better to use skillfully prepared slides. With an instrument called the microtome, it is easy to cut sections, 1/5,000 inch thick. Such sections are fastened to the slide and stained to make it easier to see the various structures. A photomicrograph—a photograph made with a microscope and camera—of a thin well-stained section is shown in Fig. 278*A*; and a few cells, more highly magnified, are shown in *B* of the same figure.

The principal structures of a cell are the *protoplasm*, the *nucleus*, and the *cell wall* (Fig. 279).

Many cells, like zoospores and gametes, have only protoplasm and nucleus; they have no cell wall. The nucleus is bounded by a *nuclear membrane*. Inside the membrane is an important substance called *chromatin;* and a small, spherical body, called the *nucleolus*. Surrounding the nucleus and filling a considerable part of the cell is the *protoplasm*. The protoplasm has been called the *physical basis of life* and the nucleus is known to be the *physical basis of heredity*.

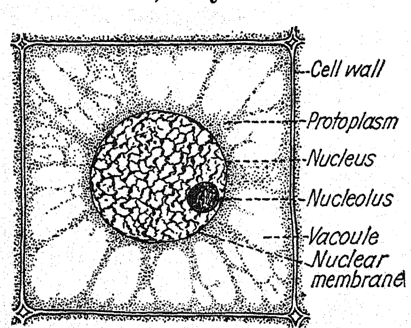


FIG. 279.—Diagram of a cell, highly magnified.

In nearly all plant cells the protoplasm contains large vacuoles filled with various liquid and semiliquid substances.

Besides the nucleus and protoplasm, cells contain other things. Many contain plastids. The *plast-* means a former. Plastids form something. Plastids which are near the light, as in green leaves, form the chlorophyll which gives leaves their green color (Fig. 280). Some plastids produce other coloring substances which give yellow, red, and brown colors. In the Algae, plastids often have striking shapes. The spiral plastid (chromatophore) of *Spirogyra* is a good example (Fig. 150). Some plastids form starch. Scrape a Potato or cut a thin section and the microscope will show an immense number of starch grains (Fig. 280*C*, *D*).

Some cells contain oil and some have so many mineral crystals that they can be tasted, as in the Wood Sorrel, *Oxalis acetosella*, which got its scientific name from the large amount of oxalic acid in its leaves (Fig. 280*B*).

Every plant and every animal starts as a single cell. The cell divides; then the two cells divide; and divisions continue until

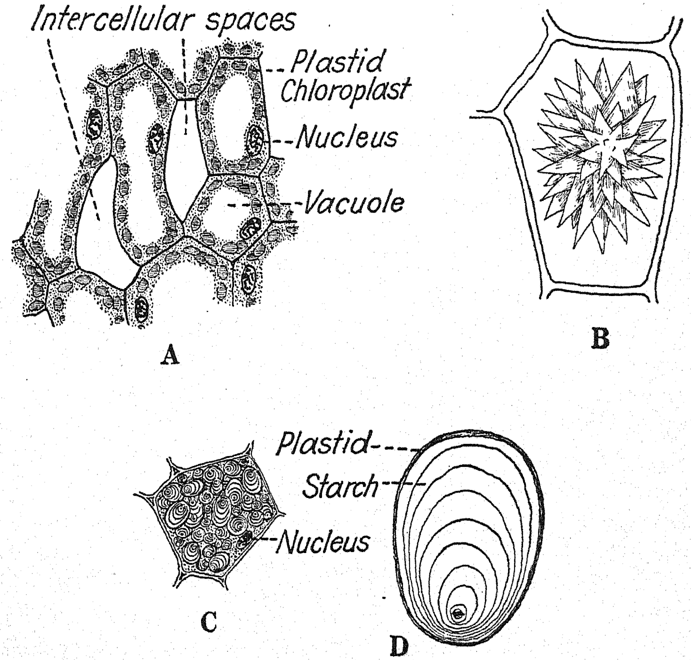


FIG. 280.—*A*, cells of Lilac leaf showing chloroplasts, × 400; *B*, calcium oxalate crystals in cell of a cycad, × 400; *C*, cell of a potato with numerous starch grains, × 200; *D*, a single starch grain, × 400.

a mature body has been built up. As the body becomes mature, reproductive cells, the sperms and eggs, are formed; a sperm unites with an egg, and the fertilized egg is the first cell of a new plant or a new animal.

Cell Division.—The whole process of cell division can be seen in the cells of a root tip. The nucleus divides, so that there are two nuclei in one cell; then a partition is formed between the two nuclei, and there are two cells where there was only one before. The details of the process are well known and can be seen with an

ordinary microscope. The principal stages of division are shown in Fig. 281.

The nucleus enlarges a little and its chromatin collects into a spiral band (Fig. 281*B*); the band breaks up into rodlike pieces, called *chromosomes C;* the chromosomes become regularly arranged and each one splits lengthwise, making two chromosomes *D*;

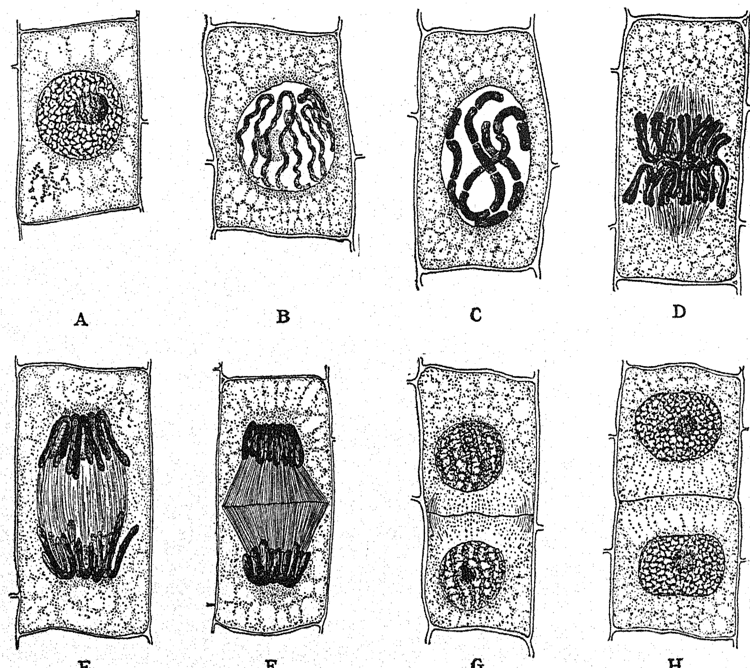


FIG. 281.—Nuclear and cell division in root tip of Onion. *A*, resting nucleus; *B*, spirem stage; *C*, spirem divided into chromosomes; *D*, metaphase, with chromosomes split; *E*, late anaphase; *F*, early telophase; *G*, late telophase; *H*, resting nucleus. × 1,200.

one of the two chromosomes resulting from each splitting moves to one end of the cell and the other moves to the opposite end *E*; the new chromosomes at each end of the cell become more closely crowded *F*; then stick together forming a spiral band *G*; which gradually assumes the appearance seen in the resting nucleus *A* and *H*. When the division is nearly completed, a new wall appears between the two new nuclei *F*, and there are two new cells, each with its own nucleus *H*.

Division takes place in this way not only in the root but also in the stem, leaf, flower, and fruit.

A remarkable thing about the process is that each plant has a definite number of chromosomes. The root tip of a Lily has 24 chromosomes in each nucleus; an Onion has 16; and *Trillium* has 12.

When a sperm unites with an egg, the number of chromosomes is doubled, and it remains double in the new plant, except when spores are to be formed. Then a cell, called a spore mother cell, divides twice, producing four spores. These two divisions are very peculiar. In a root tip the chromosomes split at every division; but in one of the two divisions in the spore mother cell there is no splitting. The result is that the nuclei in the spores have only half as many chromosomes as those in a root tip. The spore, whether it is a microspore or a megaspore, is the first cell of a gametophyte, and the reduced number of chromosomes is maintained throughout all the cells of the gametophyte; so that when a gametophyte produces an egg or a sperm, the egg and sperm have the half number of chromosomes. When the egg and sperm unite at fertilization, the number is doubled. So, the egg and sperm of the Lily have 12 chromosomes, and the fertilized egg, the first cell of the sporophyte, has 24. Similarly, the numbers in the Onion are 8 and 16; and in *Trillium,* 6 and 12.

Chromosomes have been studied in great detail because it is practically certain that they carry the hereditary characters.

Protoplasm.—The protoplasm of a cell is almost constantly in motion, except in dry seeds and spores and in other parts of the plant where the protoplasm is dried up by the heat or made dormant by the cold.

The motion is so vigorous in many cells that it can be seen with a microscope. The leaves of *Elodea,* a water plant often used in aquaria, are good for this demonstration. With a safety razor blade, cut off a fresh green leaf, mount it in a drop of water under a thin cover glass, and examine with as high a magnification as is available. The long cells in the middle of the leaf are the best. The shock of cutting the leaf may stop the movement for two or three minutes, but it will soon start. If the temperature is 70°F. or higher, the movement will be more rapid. The protoplasm itself is nearly colorless, but the green plastids are carried

along in the current, like chips on a river, so that the movement can be recognized.

If *Chara* or *Nitella* can be secured, the movements are more conspicuous. The stamen hairs of the Spider Lily (*Tradescantia*) are good. Stinging hairs of Nettles show a vigorous movement. An Onion, as you get it from the grocery, will furnish material. From a scale near the center, where the odor is strong, strip off the epidermis and mount it in a drop of water or in juice squeezed out from the Onion. In cells which will be torn off with the epidermis, the movements are quite rapid. Yellow gas light is better than white light for examining movements in the Onion.

The cell is so important and interesting that many books in many languages have been written about it. The study of the cell is called *cytology*.

Structure and Life History of Angiosperms.—The preceding study of the cell should make it easier to understand the complicated structures and life history of the Angiosperms, the highest group of the plant kingdom. As we proceed from the lower plants to the higher, some structures become larger and more complex, while others become reduced until they are very small and simple. These small simple structures are the gametophytes and they would be hard to understand, unless the gametophytes of the Liverworts, Mosses, Lycopods, Ferns, and Gymnosperms are kept in mind.

Part I dealt almost entirely with such features of the Angiosperms as can be seen without a microscope. What was said about the leaf, stem, root, flower, fruit, and seed should be kept in mind and should be reviewed, if much has been forgotten.

The Leaf.—The leaf is the laboratory of the plant. It is here that the crude materials are manufactured into food which can be used by various parts of the plant.

The microscopic structure of leaves is as various as their shapes and sizes and is related, more or less, to what they are to do. A leaf growing in the water will have a very different structure from one growing in the air; a leaf of a forest tree will be different from the leaf of a desert plant.

In a typical leaf, like that of a Lilac, the upper part, exposed to the sun, will have a different structure from the lower part, which is more or less shaded. In a leaf which stands more or

less erect, like the leaves of grasses, there will not be so much difference between the upper and lower part. The upper surface of a leaf is covered by a varnish-like substance, called *cutin*, which keeps the leaf from getting too wet, and also prevents it from wilting too rapidly when the weather is hot and dry (Fig. 282). The cutin on the lower side of the leaf may be thinner or may be entirely lacking.

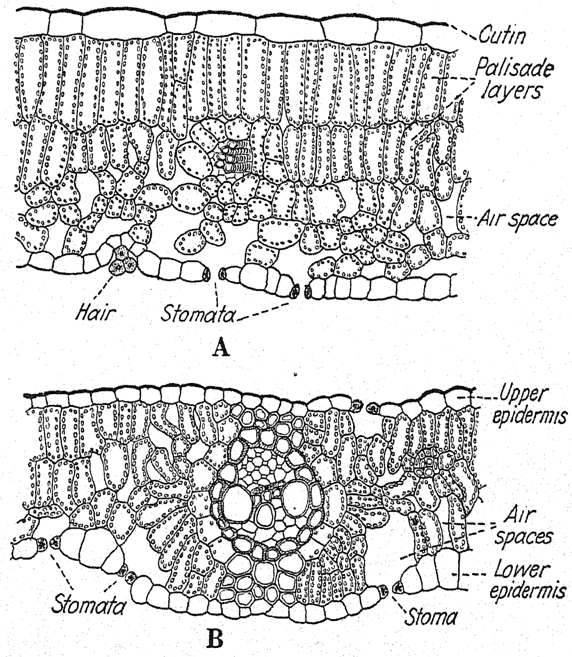


FIG. 282.—*A*, section of Lilac leaf; *B*, section of Wheat leaf. × 150.

It is easy to see that in some leaves the surface is smooth and shiny; in others it is dull; in some it is rough; and in others it is sticky. A thin section of a piece of a leaf will show that the differences in appearence are due to differences in structure. In some the surface cells are smooth, as in the Lilac; where the surface is soft and velvety, there may be short soft hairs; where it has a coarser velvety appearance, as in the Mullein, there may be rather coarse branching hairs; if the surface is sticky, there may be hairs with a knob at the end which secretes the sticky sub-

stance (Fig. 283). The most conspicuous sticky hairs are found on leaves of the Venus Fly Trap, the Sun Dew, and various Pitcher Plants, which catch and devour insects.

Beneath the epidermis the structure is just as varied. If the leaf is more or less horizontal, as in the Lilac and in most plants, the cells just beneath the epidermis are likely to be elongated, so that they present their smaller diameter to the light. These elongated cells, often just one layer of them, but sometimes more, are called *palisade* cells (Fig. 282). They are abundantly supplied with the plastids which make chlorophyll.

The cells in the lower part of the leaf are loosely arranged, because they are split apart, more or less, so that there are considerable spaces in which air and gases can circulate (Fig. 282). The veins of the leaf run mostly among these looser cells.

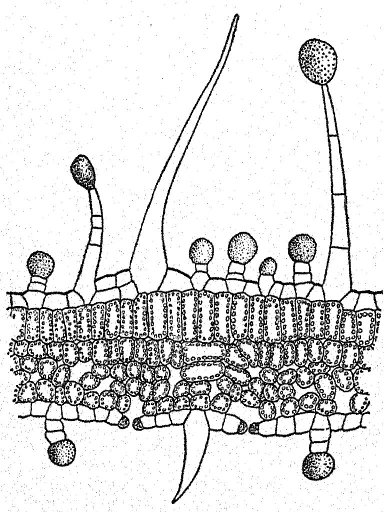


FIG. 283.—Section of *Geranium* leaf showing glandular hairs. × 150.

In the lower epidermis are the openings called stomata (Fig. 284). They open into the spaces caused by the splitting apart of the loosely arranged cells. Through the stomata gases from the air, principally carbon dioxide, enter the leaf, and oxygen escapes, purifying the air. Water vapor, escaping principally through the stomata, is partly responsible for the upward movement of sap. The stomata are very numerous, as may be seen by stripping the epidermis from the lower side of the leaf of a Lily or any other plant from which the epidermis strips off easily.

In erect leaves, like those of the Cat Tail and *Iris*, there are stomata on both sides of the leaf; but in horizontal leaves most of the stomata, or even all of them, are on the lower side. In leaves floating on the water the stomata are all on the upper surface.

Many plants growing in hot dry places have thick fleshy leaves, with deeply sunken stomata, which may be still further protected

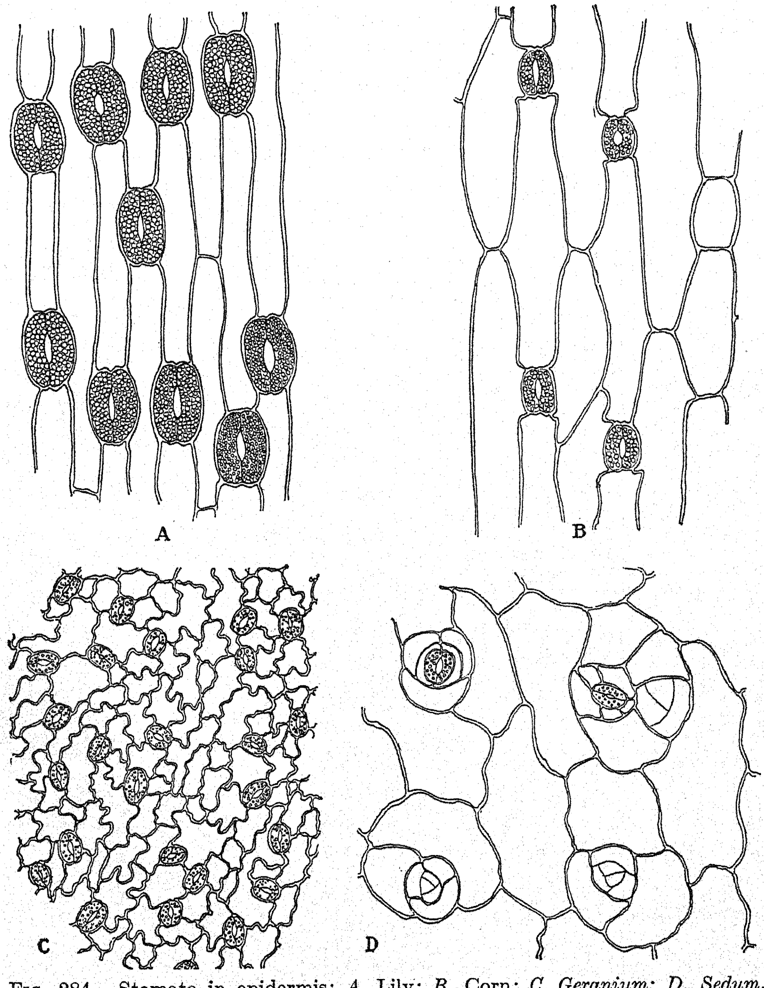


FIG. 284.—Stomata in epidermis: *A*, Lily; *B*, Corn; *C*, *Geranium;* *D*, *Sedum.* × 150.

by hairs. Such stomata are usually closed, and, when they do open, it is likely to be at night or on a rainy day, so that little moisture escapes.

The veins in the leaf not only conduct materials from one place to another but furnish support to the softer parts which change crude materials into usable food. The veins are often surrounded by thick-walled cells which give additional support, as in the long slender leaves of Grasses (Fig. 282).

In the immense leaves of some of the Palms the veins, with thick-walled surrounding cells, become so crowded and woody that the leaf stalks can be cut into small boards and used like other lumber.

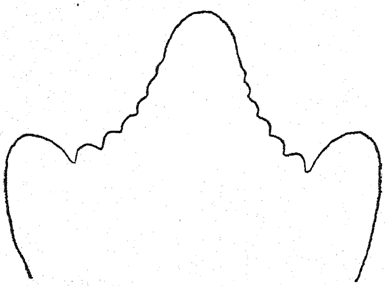


FIG. 285.—Longitudinal section of stem tip of *Hippuris* (Mare's Tail), showing origin of leaves. × 90.

Leaves arise very near the tip of the main stem or a branch. The earliest stages are seen only in buds and, even then, only in young buds; for the mature bud, as it rests for the winter, has the leaves well outlined. In a young bud the leaves appear as rounded knobs close to the tip of the stem (Fig. 285). Their cells are very much alike, but later they develop into the various kinds of cells which have just been described.

The Stem.—The structure and functions of the stem have attracted interest ever since people began to study plants. What forces conduct sap to the top of a high tree? How does a stem grow until it becomes several feet in diameter? Why is it safe to climb a Hickory tree and dangerous to climb a Willow? Some wood is hard and some is soft; some of the hard wood is elastic and some is brittle; there are differences even between woods which are hard and elastic. Every archer knows that Yew makes a better bow than Hickory. Why does the War Department make all its rifle stocks of Black Walnut? Why is some wood white, some black, some dark brown, and some red, green, or yellow? One could spend a lifetime studying stems and still there would be questions to answer.

Many questions, and some of them the most important, are being answered by a study of the structure of stems. Colors of the wood are due to chemical composition and structure.

The *Geranium*, so common in cultivation and so popular in window boxes, furnishes good material for a study of the stem. A cross-section very near the top of a plant shows a pith at the center, surrounded by a zone of woody bundles, which are themselves surrounded by a cortex. The cortex is surrounded by the epidermis which is only one layer of cells thick (Fig. 286*A*).

The pith consists of very uniform cells which are more or less split apart and rounded off. In many plants the splitting continues until the cells of the pith become entirely separated from each other. They then dissolve, forming a liquid which is absorbed

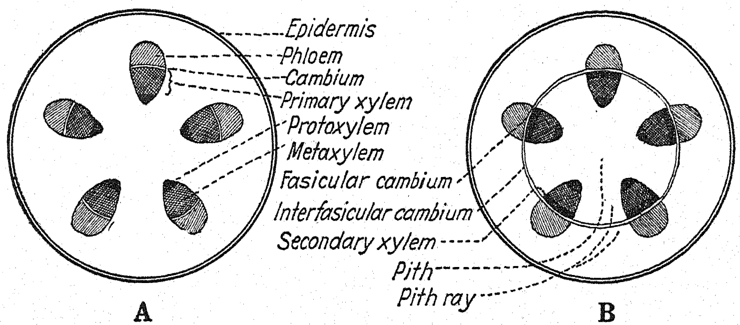


FIG. 286.—Diagrams of cross-sections of stems before and after the beginning of secondary growth.

by the bundles and neighboring cells. With the pith dissolved and absorbed, the stem becomes hollow, as in Wheat, Oats, and many other Grasses, even such large ones as the Bamboo. All herbs with hollow stems are solid at the tips of stems and branches and become hollow by losing their pith.

In many herbs and shrubs the cells of the pith round off but, instead of becoming dissolved, they get dry and white, as in the pith of the Elder and Sunflower. Surrounding the pith is a zone of bundles. Very near the top of the plant a cross-section usually shows five bundles (Fig. 286*A*).

On the side next the pith the bundle consists of thick-walled woody cells called *xylem*. On the outside, next the cortex, the cells have thinner walls and are called *phloem* cells. Between the xylem and the phloem is a layer of very delicate thin-walled cells, called the *cambium*, the cells of which keep dividing and thus

add new cells to the phloem on the outside and to the xylem on the inside.

Between bundles, connecting the pith and cortex, are the *pith rays*. Sections showing the features mentioned up to this point are not easy to cut, because the stem, at this level, is so small and soft that it is hard to hold in one's fingers.

A little farther down from the tip of the plant, a cross-section shows that a cambium has appeared in the pith rays, joining the cambium of the bundles on both sides. The cambium in the bundle is called *fasicular cambium* and that in the ray is called *interfasicular cambium*. (Fig. 286*B*). Together, they make a continuous ring of cambium which produces wood on the inside and phloem on the outside.

In sections cut near the top of the plant, the cells of the cortex are very much alike but, lower down, there is a zone of cells which becomes very much thickened, adding greatly to the strength of the stem (Fig. 287). In many herbs the cortex is strengthened by various groups of thick-walled cells.

Several inches down from the top of the stem a cambium appears in the cortex just below the epidermis. It forms a complete ring, producing cells in regular rows, and, since these cells often become corky, it is called the *cork cambium* (Fig. 287). In the Cork Oak the cork cambium is very vigorous and produces a thick layer from which corks for bottles are made.

The cortex is bounded by the epidermis, the outermost layer of cells of the stem. In the *Geranium* some of the cells of the epidermis grow out into long hairs with large knobs on the end. These knobs produce the substance which gives the *Geranium* its pleasant odor (Fig. 283). They are all over the upper part of the stem and on the leaves, but, lower down where the stem is older, the knobs dry up, and, at the bottom of old stems, the whole hair is lost off and the stem becomes smooth.

The cells next the pith are quite different from the rest. They are much longer than wide and their cross-walls soon break down, so that cells of a row form one continuous tube, called a vessel. The Lycopods, Ferns, and Seed Plants are called Vascular Plants (Vessel Plants) because they have vessels formed in this way. The inner surface of the vessel is marked with spiral bands. If a cut is made around a small herbaceous stem

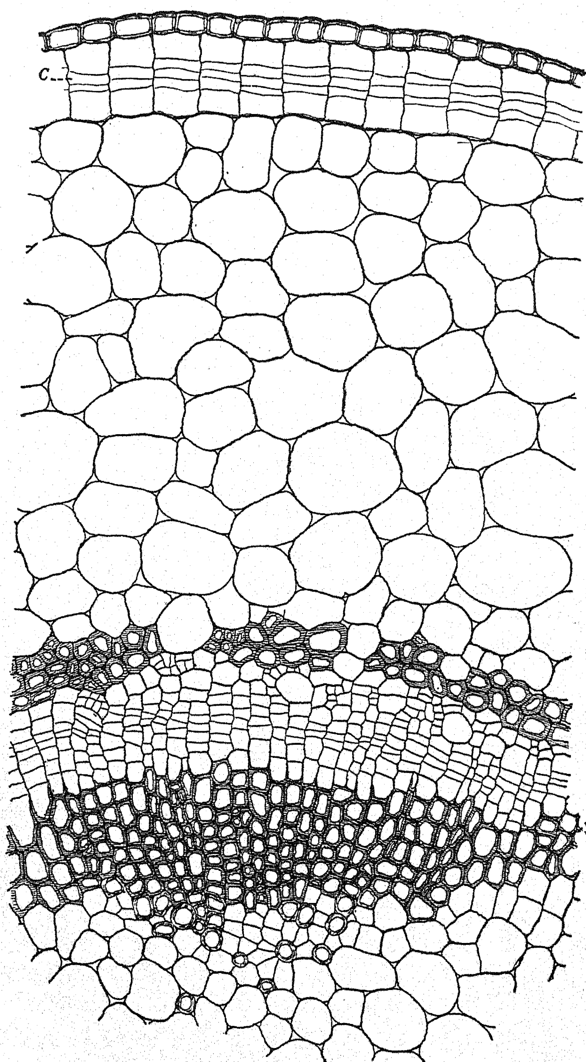
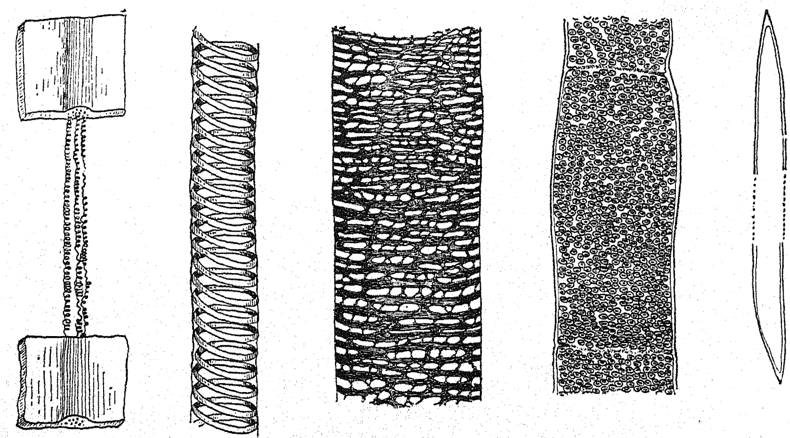


FIG. 287.—Part of cross-section of *Geranium* stem. The cork cambium, *C*, is beginning to produce the secondary cortex. × 150.

nearly down to the pith and the stem is then broken apart gently, the spirals can be seen without a microscope. It is much easier to see them in the veins of a leaf. If a piece of a leaf, about an inch long and a quarter of an inch wide, containing a strong vein be broken in two, the spirals will be seen between the two pieces and may be so strong that, by holding one piece, the other may be suspended by the spirals (Fig. 288*A*, *B*). These spirals are the earliest woody part of the bundle and, on that



A B C D E

FIG. 288.—*A*, spiral vessels (protoxylem) in leaf of *Geranium; B*, part of spiral vessel of Pumpkin; *C*, part of reticulate vessel; *D*, part of pitted vessel; *C*, a tracheid. *C*, *D*, and *E*, Sunflower.

account, are called the *protoxylem*. In the Angiosperms the protoxylem is always the innermost part of the xylem, bordering on the pith, so that the woody cylinder is an *endarch siphonostele*.

There are other vessels between the protoxylem and the cambium; but they do not pull out very well, because the markings are not spiral. They have pits or netlike markings (Fig. 288*C*, *D*). Many of the cells of the wood simply get long and thick walled; their end walls do not break down so as to form vessels. They are generally pointed at both ends (Fig. 283*E*). Such cells are called *tracheids*. Nearly all of the woody cells formed late in the season are of this type, and it will be remembered that the wood of Gymnosperms is made up, almost entirely, of tracheids with bordered pits.

The cells of the phloem are quite different. Most of them have thin walls and there is no breaking down of cross-walls to form vessels. The *Geranium* and most plants are unfavorable for a study of the phloem, because the structures are so small. The Pumpkin and other members of the Pumpkin Family, like the Cucumber, Squash, Cantaloupe, and Watermelon, are better.

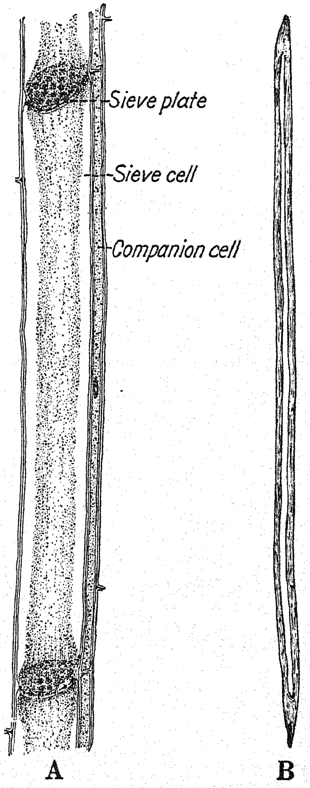


FIG. 289.—*A*, a sieve cell and companion cell, and *B*, a phloem tracheid of Pumpkin. × 285.

A longitudinal section through the phloem of a Pumpkin vine shows some large long cells with thick cross-walls. These are the *sieve tubes*, and they are very important in transporting the usable food materials which have been manufactured in the leaves and other green parts of the plant. The thick cross-walls are called *sieve plates* (Fig. 289*A*). Many of the sieve tubes are accompanied by long narrow cells called *companion cells.* They are found only in the phloem of Angiosperms. There are other cells in the phloem, especially long thick-walled tracheids, looking like the tracheids in the wood, but they are soft and do not have pits (Fig. 289*B*). Basswood (Bast-wood) gets its name from the great number of these cells.

In trees and shrubs the wood forms the principal part of the stem. The pith is comparatively small, and, in most trees, the cortex is entirely lacking, except at the tips of the stem and branches. The corky layers scale off, and, as the tree grows, the bark cracks in characteristic ways, so that one recognizes the Hickory, Sycamore, *Eucalyptus*, Ash, and others by their bark. As the bark scales off, all the cortex is lost and, in older trees, is renewed from the outer part of the phloem.

The bark has little commercial value except in a few forms like the Cork Oak, in Cinnamon, and in others in which it is used for drugs.

Lumber is made entirely from secondary wood formed by the cambium. In the spring the cambium is very active and some of the cells which it produces become large vessels; in summer, growth is not so vigorous, the cells are smaller with practically no vessels, the new cells being tracheids with very thick walls;

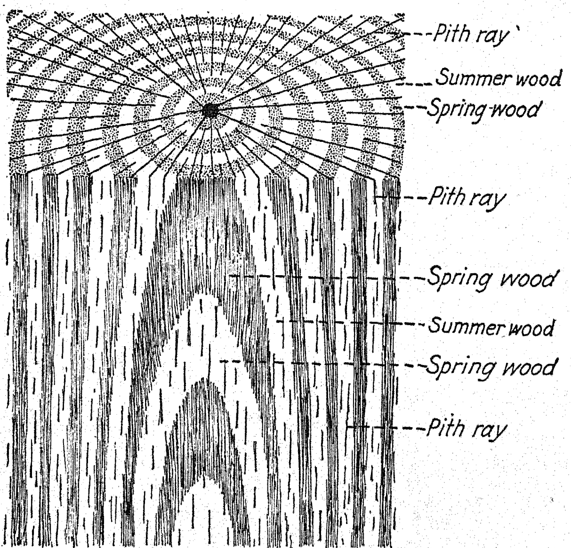


FIG. 290.—Diagram of a block of Oak, showing relation of annual rings to the grain.

and in the autumn there is no growth at all in temperate regions. During the autumn and winter the cambium rests; but when spring comes around again, there are more big cells with numerous vessels. The largest cells of the spring wood, coming next the smallest cells of the summer wood, give the appearance of the ring, called the annual ring. The age of a tree can be determined by counting the number of annual rings (Fig. 43).

The grain of wood depends almost entirely upon the annual rings. The wood formed in the spring, having larger cells and

many vessels, is not so hard as the summer wood, with its smaller, thick-walled cells. The result is that there are alternating bands of softer and harder wood. If a board should be cut perfectly straight, there would be no grain, except straight lines; but such a cut is hardly ever made, and the least deviation gives the appearance shown in Fig. 290. Wherever the cut crosses an annual ring, there is an arch in the grain, the darker part made of the spring wood, with its large vessels, and the lighter, smoother part made up of the harder summer wood.

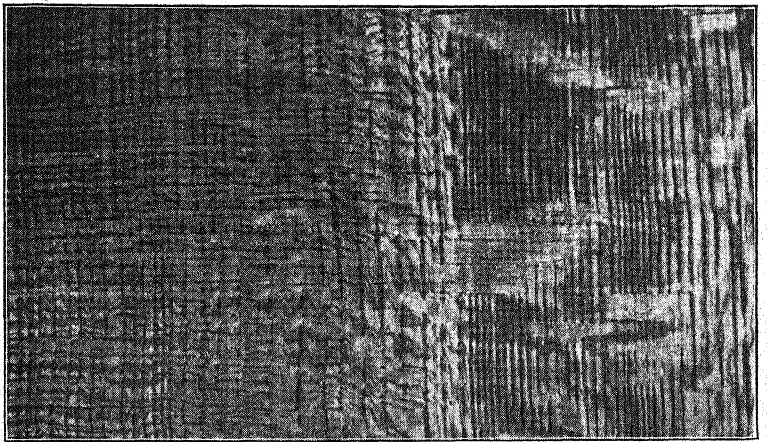


FIG. 291.—Photograph of quarter-sawed Oak, showing relation of pith rays and annual rings to the grain.

Where the vessels of the spring wood are very large, as in the Oak, the carpenter or cabinetmaker, before oiling or varnishing, "fills" the wood with a "filler," which fills the cut vessels and makes the surface as smooth as that of the hard summer wood. In many woods, but especially in Oak, some coloring matter is put into the filler, so that the vessels appear almost black.

In Oak, and in many others, the pith rays are an important part of the grain, if the board is cut parallel with the rays, because the pith rays are very large and their wood is the hardest in the tree. When a board is cut parallel with the ray—a radial section—the rays form the light-colored patches characteristic of quarter-sawed Oak (Fig. 291). In pioneer days, when farmers

made their own shingles, they split them from Oak blocks, always splitting parallel with the rays, because the numerous hard whitish patches made better shingles.

In Beech the rays are smaller and shorter, but they give character to the grain. When the rays are so small that they cannot be seen without a microscope, they do not have any visible effect upon the grain, except that very numerous small rays give a satin-like finish.

The microscopic structure of stems was studied more than 200 years ago, when microscopes were very poor. They used little globules of glass, as small as a pinhead and ground off so as to get a hemispherical piece which could be fastened in a hole in piece of lead, thus making it easier to handle. Each worker made his own microscopes. With such a lens, Nehemiah Grew, a preacher botanist, made pictures of stems which, in their general features, are almost as good as those made today.

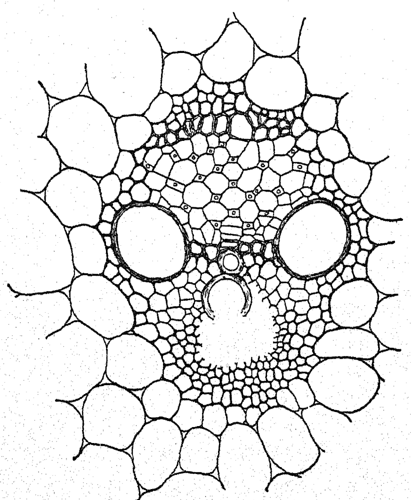


FIG. 292.—Vascular bundle of Corn. × 10.

A cross-section of the stem of a Dicotyl usually shows a pith, with a zone of wood between the pith and the cortex; the Monocotyls usually have scattered bundles, as in Corn (Figs. 41, 42). The bundle in the Monocotyl does not have any cambium between the xylem and phloem, and so there is not much increase in diameter and no annual rings, except in a few treelike Monocotyls, such as *Yucca*.

The bundle in Corn shows the phloem very well, with its sieve tubes and small companion cells. There are no phloem tracheids in this bundle. Each bundle has two large vessels with numerous pits. The protoxylem breaks down early, so that there is a hole opposite the phloem, which may show a ring or two of the protoxylem for a while (Fig. 292).

A branch starts like a leaf, as a small rounded mass of cells, but the position is different. The leaf starts directly from the stem, just below the stem tip; while the branch starts in the axil of a leaf, the axil being the angle between the upper part of the leaf and the stem (Fig. 293). The branch behaves like the main stem, producing leaves, flowers, and more branches.

Some claim that the leaf is the most important part of the plant, the function of the root being to get materials, and the function of the stem being to conduct them to the leaf, where crude materials are transformed into usable foods. The leaf is very important; and the stem, with its branches, does conduct materials, the movement of crude materials being, principally, up; and the movement of usable foods being, principally, down; but, in a tree, much of the food is used by the stem, contributing to its growth. At the reproductive period, great quantities of food are used in the production of flowers, fruits, and seeds. Some of the factors concerned in the movements of materials are mentioned on page 52.

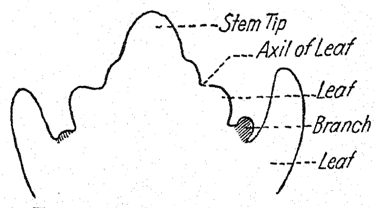


FIG. 293.—Stem tip of Ceratophyllum (Hornwort), showing the origin of branches. × 60.

There is a constant passage through cell walls and only liquids can pass. Consequently, food in any other form than liquid must be changed into the liquid condition. The changing of starch, which is not liquid, into a sugar, which may be liquid, is called *digestion*. Other foods are also digested. The study of these changes and the agents which bring them about are important features of modern plant physiology, requiring a considerable knowledge of chemistry.

Much of the food coming to the stem from the leaf reaches the cambium, where it is transformed into living protoplasm which enables the cells of the cambium to divide rapidly. Cells cut off from the cambium on the side toward the pith become woody and build up the body of the stem; while those cut off on the side toward the cortex produce phloem.

The Root.—The various kinds of roots, with their shapes and functions, have been studied in Part I.

Most roots have root hairs which absorb water containing various substances in solution. These substances are passed from the root hairs through the cells of the cortex and to the woody bundles, which conduct such crude sap to the stem and up to the leaves, where it is converted into usable food. A root hair consists of a single epidermal cell, very thin walled and very much elongated (Fig. 294).

Some roots have enormous numbers of root hairs, some have a few, and some have none at all; some have hairs when growing in soil or in damp air, but none while growing in water. Roots can absorb materials, therefore, whether they have root hairs or not.

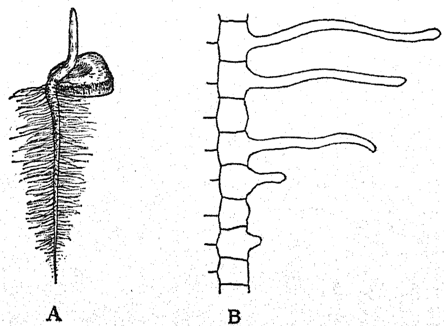


FIG. 294.—Root hairs of Corn. *A*, about natural size; *B*, × 150.

The cells of the cortex are thin walled, and there are seldom any of the thick-walled strengthening cells, which are so common in the cortex of stems. The inner layer of cells of the cortex, called the *endodermis*, often has thick walls, especially in Monocotyls (Fig. 295).

The young woody cylinder of a root is very different from that of a stem, for the protoxylem is always at the outside (exarch), and the phloem comes between the bundles (Fig. 295).

In most plants there is no pith in the root, but, where it is present, it is like the pith of a stem, consisting of thin-walled cells very much split apart.

In trees and shrubs, where the roots become larger, a cambium is formed which, at first, has a wavy outline when seen in cross-section, but which soon becomes circular, so that a section of a

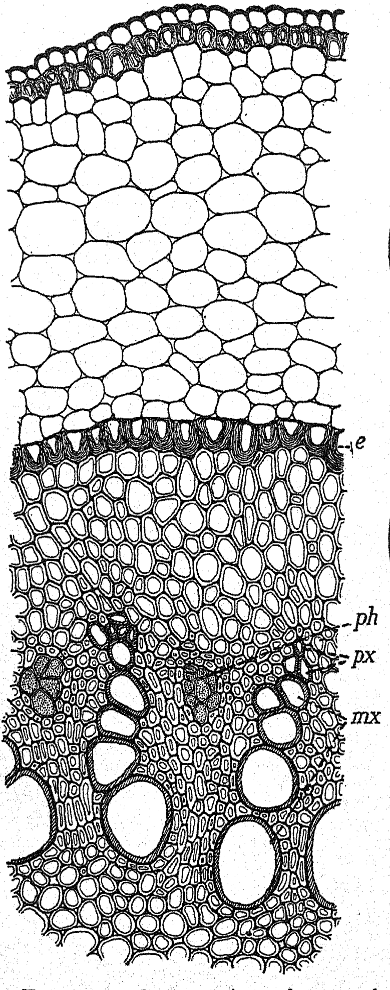


FIG. 295.—Cross-section of root of *Smilax*, showing *e*, prominent endodermis; *ph*, phloem; *px*, protoxylem; *mx*, metaxylem. × 150.

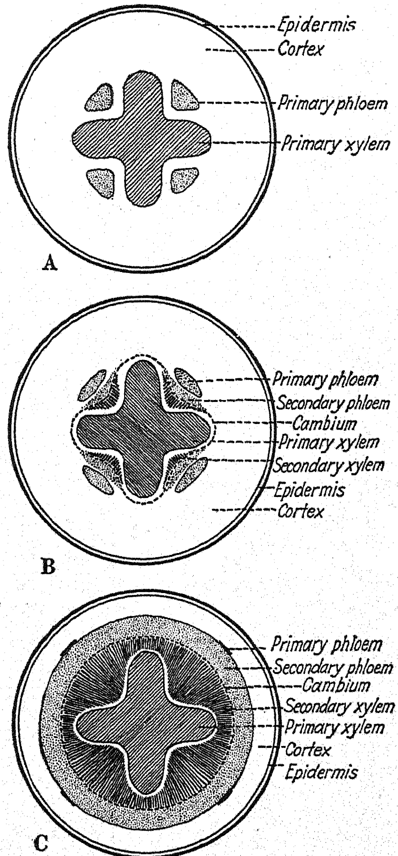


FIG. 296.—Diagrams of cross-sections of roots. *A*, showing only primary structures; *B*, after cambium ring is complete and secondary xylem and phloem have begun to develop; *C*, a later stage with considerable xylem and phloem.

large root looks like the section of a stem, and its age can be determined by counting the annual rings (Fig. 296).

The origin of a secondary root is very different from that of a branch, for the branch comes from the young cells at the tip of the stem. The secondary root does not come from the young cells at the tip of the main root, but from the *pericycle*, a layer of cells just beneath the endodermis. This layer behaves like a cambium. Little patches of it, opposite protoxylem points, divide and produce a rounded mass of cells, which continue to divide and develop into a root (Fig. 297).

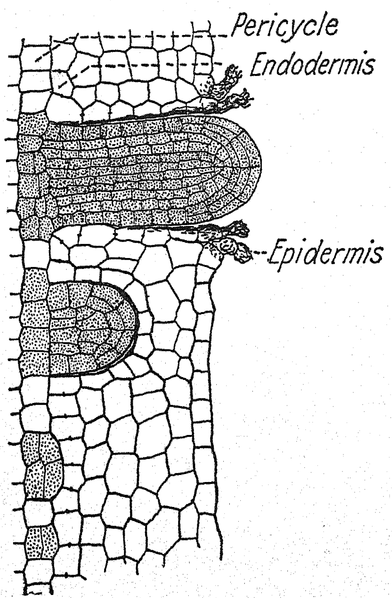


FIG. 297.—Diagram of origin of secondary roots.

The young root partly dissolves the cells of the cortex in front of it and partly crushes them until it breaks out. Even without a microscope, it is easy to see that the side root has fractured the cortex in getting out, just as if a nail had been driven through.

The Flower.—The most important parts of a flower which can be seen with the naked eye were studied in Part I; but their origin and development, as studied with a microscope, present new problems.

A flower is really a very much shortened stem or branch, bearing structures which start like leaves, but which become sepals, petals, stamens, and carpels. The sepals come first and are often somewhat leaflike; the petals come next, are less leaflike, and are usually colored; then come the stamens and carpels which—except in rare cases—have lost nearly all resemblance to leaves.

A buttercup is a good flower to start with. A section of a very young flower shows rounded elevations just below the tip. The one nearest the tip will become a petal and the one just

below will become a sepal (Fig. 298*A*). In a slightly older flower the rounded elevations at the bottom, looking just like those in *A*, will become stamens (Fig. 298*B*); and in the same flower, the rounded elevations nearest the tip will become carpels. The rounded elevations which finally become sepals, petals, stamens, and carpels look alike when they start, and also look just like

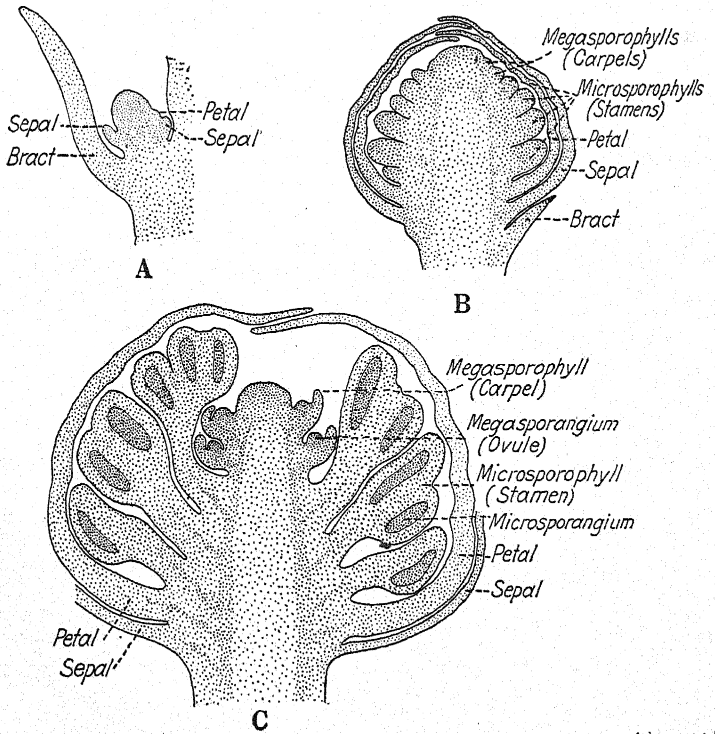


FIG. 298.—Floral development in the Buttercup (*Ranunculus acris*). × 70

very young leaves or branches; but, as the flower gets older, the stamens and carpels look very different (Fig. 298*C*). All of the parts, when very young, consist of cells which are much alike, but they gradually become different. What causes the difference is still a mystery. To say that it is heredity merely names the difficulty, it does not explain anything.

Other flowers show, fundamentally, the same kind of development as the Buttercup; but there are endless differences in details,

In the Shepherd's Purse the sepals come first, followed by stamens and carpels; the petals, which usually come second, come last (Fig. 299).

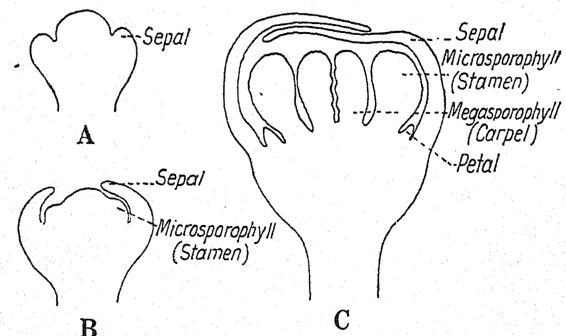


FIG. 299.—Floral development in Shepherd's Purse (*Capsella bursa pastoris*). × 85.

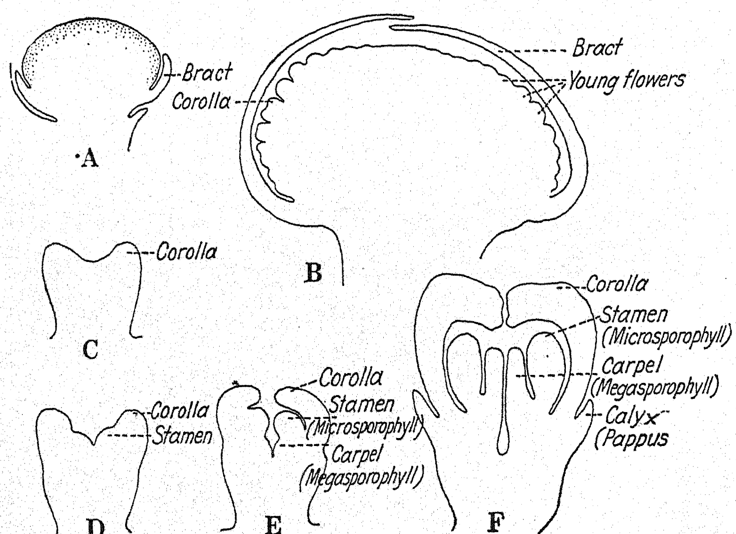


FIG. 300.—Floral development in Fleabane (*Erigeron philadelphicus*). *A* and *B* × 35; *C*, *D*, *E*, and *F*, × 150.

The Fleabane illustrates floral development in the great Sunflower Family. The first parts to appear are the leaflike bracts surrounding the whole cluster of flowers, all of which are to be formed from the shaded part in Fig. 300*A*. Each of the rounded

elevations, which look like a young sepal, petal, stamen, or carpel of the Buttercup, is to become a whole flower. The corolla appears first, followed by the stamens and carpels. The calyx, which in this flower becomes feathery, as in the Dandelion, comes last (Fig. 300*F*).

It is an interesting fact that in all trees and shrubs and in many perennial herbs, the flowers are formed in the autumn, remain dormant in the winter, and bloom the next spring.

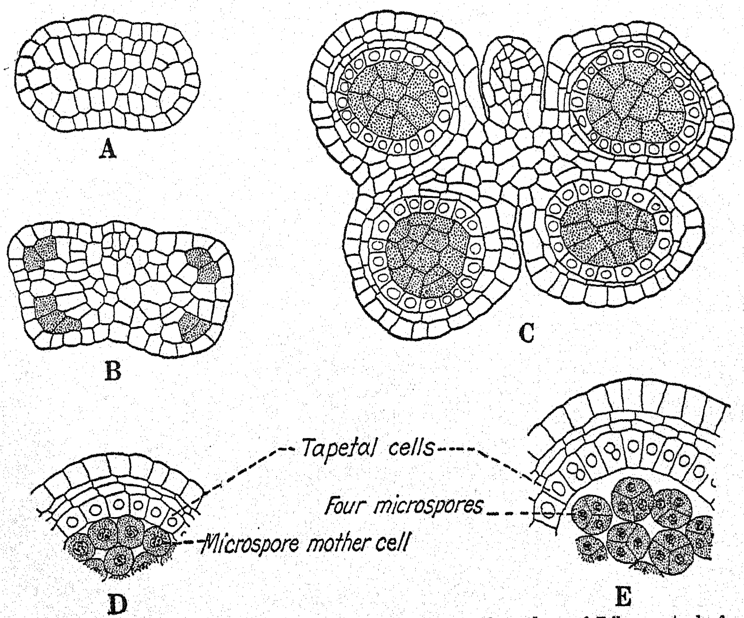


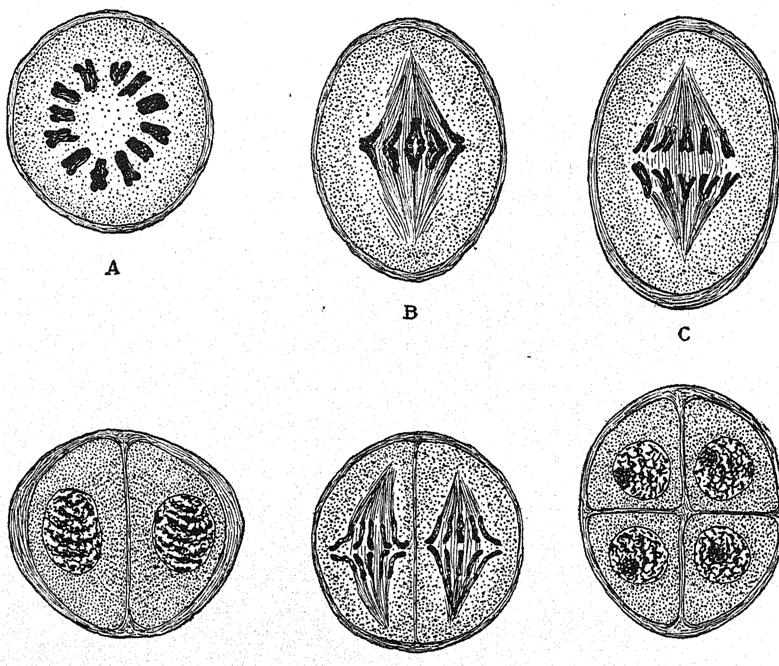
FIG. 301.—Cross-section showing development of anther of Lily. *A*, before any spore tissue can be recognized; *B*, early spore producing cells (dotted) recognizable; *C*, cells of spore producing tissue have reached the spore mother cell stage, but have not yet rounded off; *D*, spore mother cells have rounded off; *E*, each spore mother cell has produced four microspores. × 300.

The sepals are usually green and more leaflike than the other parts of the flower, but their structure is simpler than that of leaves, with more uniform cells and not so many veins. The petals have a still simpler structure with uniform cells and few veins.

The stamen usually bears no resemblance to a leaf, except that there is a stalk with a broader part, the anther, at the top. There

is only one vein in the stalk, and it does not branch in the anther. The stamen is a *microsporophyll.*

The anther, when very young, consists of cells which look alike; but, as it gets older, a cross-section shows four groups of



A B C D E F

FIG. 302.—Reduction of chromosomes in spore mother cells of Lily. *A*, bird's eye view of metaphase showing 12 pairs of chromosomes; *B*, one chromosome of each pair is starting for one pole and the other for the opposite pole; *C*, anaphase, each of the 12 chromosomes starting for each pole in *B* is seen to be made up of two chromosomes, so that 24 chromosomes are going to each pole; *D*, each nucleus of this two-cell stage contains 24 chromosomes; *E*, the 24 chromosomes of each nucleus of *D* are being distributed, 12 to each pole, so that each nucleus in *F* contains 12 chromosomes. The four cells of *F* are young microspores. × 530.

cells with denser contents. These are four young microsporangia (Figs. 66, 85). The denser cells split apart from each other and round off. They are then called *microspore—mother—cells,* because each one will divide twice and produce four microspores (Fig. 301, 302).

During these two divisions by which four microspores are produced from each microspore mother cell, the number of chromosomes is reduced to one-half the number found in the leaf, stem, root, and other vegetative parts of the plant. In the first division, as one sees it in a Lily, there are 12 pairs of chromosomes.

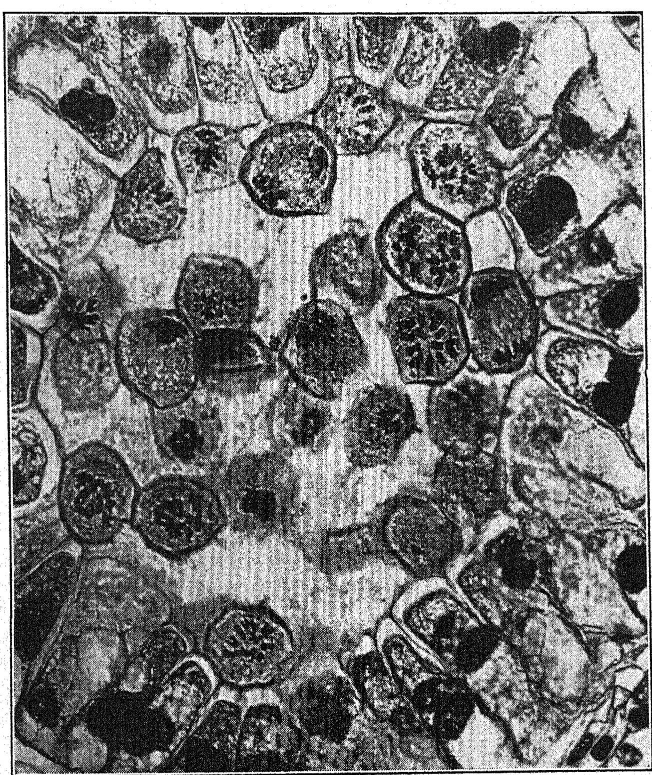


FIG. 303.—Photomicrograph of dividing microspore mother cells in Lily. × 250. (*Negative by Dr. C. Y. Chang.*)

One chromosome of each pair goes to each of the two new nuclei (Fig. 302*A*, *B*, *C*). At the second division, each chromosome divides lengthwise, producing two chromosomes, one of which goes to one new nucleus, and the other, to the other new nucleus (Fig. 302*D*, *E*, *F*).

Each of the four microspores thus formed has 12 chromosomes in its nucleus. For a while the microspores hang together in

fours, but they soon separate and round off (Fig. 301*D*). The group of microspore mother cells and the young microspores which they produce are surrounded by a nourishing layer called the *tapetum* (Fig. 301; see also Figs. 85, 303). The actual appearance of a part of a microsporangium of a Lily during the division of the microspore mother cell is shown in the photomicrograph, Fig. 303.

The microspore is the first cell of the male gametophyte. It has two spore coats, the *exine*, or outer coat, which is rather hard, and the *intine*, or inner coat, which is softer.

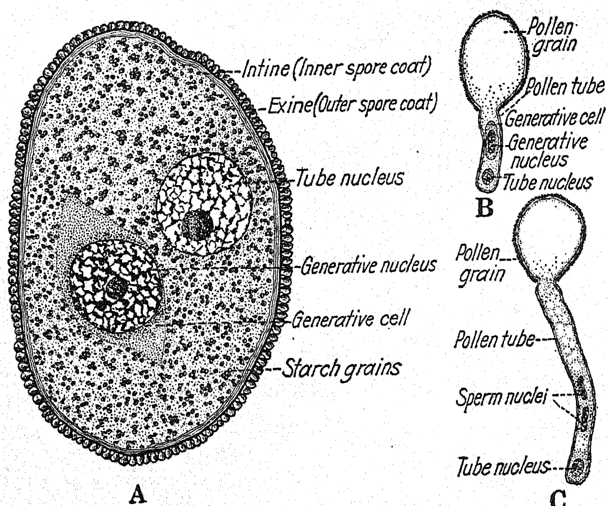


FIG. 304.—*A*, pollen grain of Lily (*Lilium canadense*) at the time of shading, × 1,000; *B* and *C*, germinating pollen grains of Iris versicolor. × 200.

The young microspore has one nucleus, which soon divides, forming the *tube nucleus* and the *generative nucleus* (Fig. 304*A*). In some plants the generative nucleus divides to form the two sperm nuclei before the pollen is shed from the anther, as in the Sunflower; but in others the division occurs after the pollen grain (microspore) has reached the stigma, as in the Lily.

After reaching the stigma, the intine of the pollen grain pushes out through a pore in the exine, forming a *pollen tube* which grows down to the ovule and finally reaches the egg. The microspore with the pollen tube, containing the tube nucleus and the two

sperm nuclei, constitute the mature male gametophyte (Fig. 304*B*, *C*).

The innermost part of the flower is the pistil, as in the Lily, or a group of pistils, as in the Buttercup and Strawberry. The pistil consists of a single megasporophyll, with its edges curved around and grown together so as to form a single cavity, as in the Buttercup and Bean; or it may consist of two or more megasporophylls united so as to form one or more cavities. In the Catch Fly there are three megasporophylls which unite so as to form only one cavity; in the Lily three megasporophylls unite so as to form three cavities. It often happens that the tops

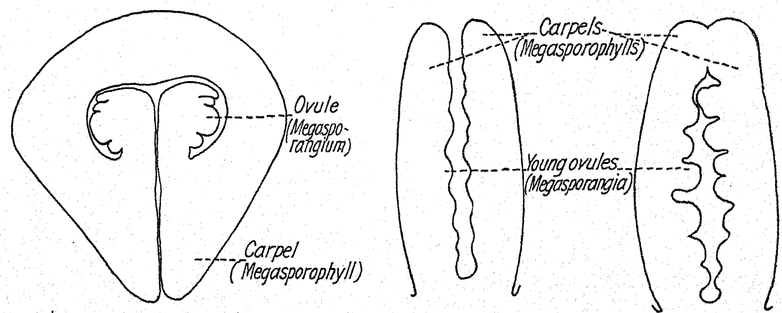


FIG. 305.—Single carpel (simple ovary) of *Firmiana*. *B* and *C*, two carpels forming the compound ovary of Shepherd's Purse (*Capsella bursa-pastoris*). × 150.

of the megasporophylls, which constitute the stigma, do not unite, so that the stigma is branched or lobed. The number of branches or lobes then shows how many sporophylls make up the pistil, for the branches or lobes are merely the tips of the sporophylls. Megasporophylls are generally called *carpels* (Fig. 305). Seeds are usually borne on the infolded edges of the carpels.

When young, the structure which is to become a seed is called an *ovule*. It would be better to call it a *megasporangium*, because it is a sporangium containing megaspores.

A cross-section of a Lily ovary shows six ovules (Fig. 306). The young ovule contains, at its tip, a *megaspore mother cell*, which is much larger than the surrounding cells (Fig. 307). As the ovule grows, one or two integuments grow up around the

central part which contains the megaspore mother cell (Figs. 307*B*, 308). The megaspore mother cell, like the microspore mother cell, divides twice and forms four spores which, in nearly all[1] seed plants, are arranged in a row (Fig. 308*B*). All four are megaspores, but one of them grows and absorbs the other three, so that one megaspore becomes large, while the other three become weak and finally disappear. The megaspore is the first cell of the female gametophyte. In Angiosperms the female gametophyte is very much reduced, consisting of only

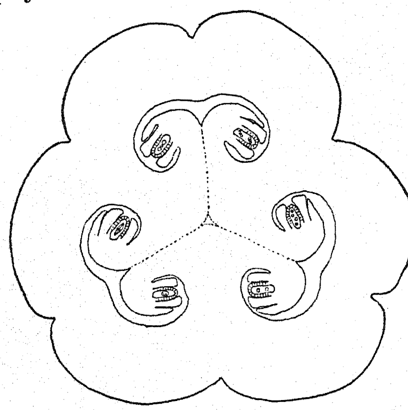


FIG. 306.—Cross-section of compound ovary of Lily, made up of three carpels bearing ovules on the inturned margins. × 30.

eight nuclei. Around one of these nuclei—the one nearest the micropyle—a single egg is formed, while the two nuclei at the sides of the egg form two peculiar cells called *synergids* (helpers). At the opposite end, three nuclei form the *antipodal cells;* and between these two groups of three cells each, the other two nuclei, called the *polar nuclei*, come together and unite to form a single nucleus, called the *endosperm nucleus*. The female gametophyte is generally called the *embryo sac*, because the embryo develops in it (Fig. 308*C*). There are many forms of embryo sacs in Angiosperms, but nearly all of them have one egg, two synergids, three antipodal cells, and two polar nuclei which unite to form the endosperm nucleus.

[1] In the Lily, Tulip, and a few others, the four megaspore nuclei are not separated by cell walls and all four megaspores take part in forming the embryo sac.

Fertilization.—A fusion of two gametes began early in the development of the plant kingdom. Most of the Algae and Fungi have this kind of reproduction; and many of them reached the stage in which one gamete is much larger than the other, so that the larger gamete is an egg and the smaller one a sperm. Above the Algae and Fungi there is no union of equal gametes; everywhere there is a union of a small sperm with a large egg. When the uniting gametes are of the same size, the process is called

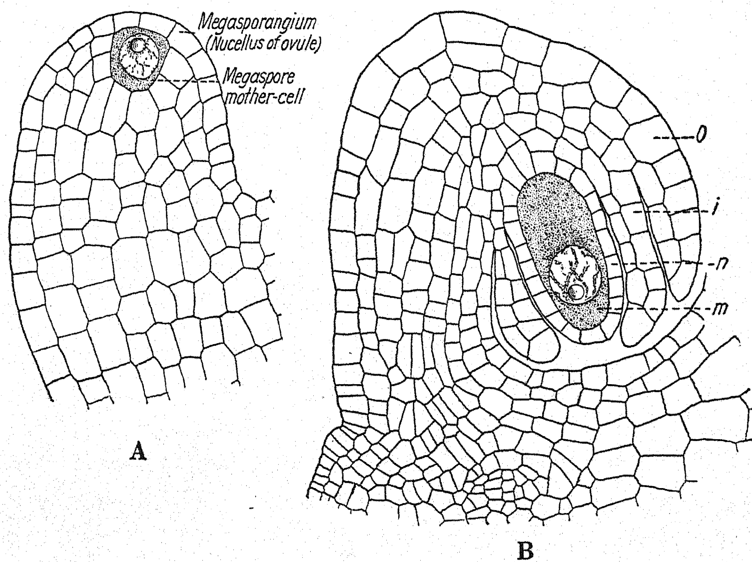


FIG. 307.—*A*, young megasporangium of Lily before appearance of integuments; *B*, later stages after both integuments have appeared. × 110.

conjugation; but when they are unequal, so that one may be called a sperm and the other an egg, the process is called *fertilization.*

In the Angiosperms the pollen is blown to the stigma by the wind or is carried there by insects. If there are three nuclei in the pollen grain, the pollen tube grows down to the ovule rather rapidly, often in a couple of days, for two of the nuclei are sperms, and sperms live only a short time; but if there are only two nuclei in the pollen grain, the growth is slower, and the division of the generative nucleus to form two sperms takes place in the pollen tube. In this case the time required for the pollen tube to grow

down from the stigma to the ovule varies from three or four days in some of the Lilies to a year in some of the Oaks.

The end of the pollen tube enters the micropyle, swells up, then bursts and discharges its nuclei. One of the two sperm nuclei enters the egg and unites with its nucleus, while the other

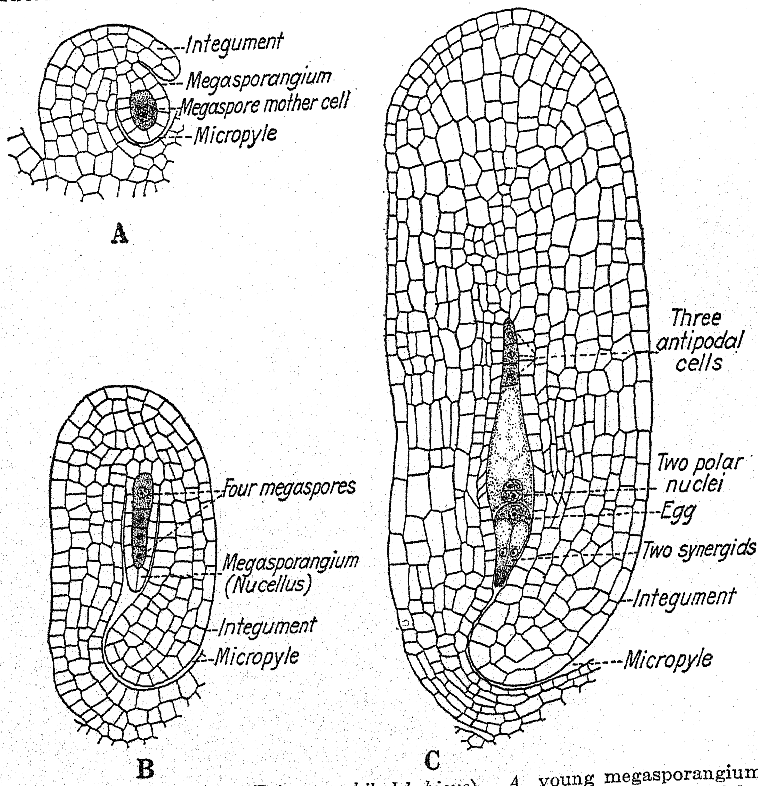


FIG. 308.—Fleabane (*Erigeron philadelphicus*). *A*, young megasporangium, the single integument beginning to develop; *B*, the megaspore mother cell has produced a row of four megaspores; *C*, an embryo sac has been developed by the germination of the largest of the four megaspores. × 185.

sperm nucleus unites with the endosperm nucleus (Fig. 309). One of the sperm nuclei stimulates the egg and causes it to develop into a new plant; while the other stimulates the endosperm nucleus so that it divides repeatedly and produces the endosperm, which is the principal edible part of Corn, Wheat, Oats, Cocoanut, Almond, and many other seeds.

Since there are two fusions—one sperm fusing (uniting) with the egg and the other fusing with the endosperm nucleus—the process is called *double fertilization*. Since the two polar nuclei and a sperm nucleus unite to form the endosperm nucleus, this process is called *triple fusion* (Fig. 309).

Embryo and Endosperm.—The embryo and endosperm develop together, the endosperm usually starting a little sooner and thus furnishing food for the young embryo (Fig. 310).

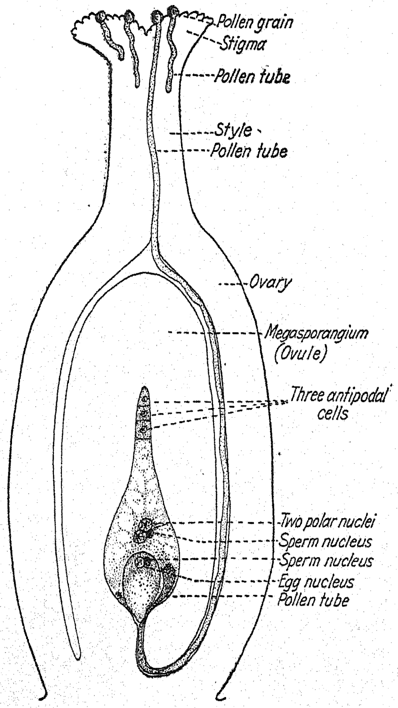


FIG. 309.—Diagram showing embryo sac and other structures at the time of fertilization.

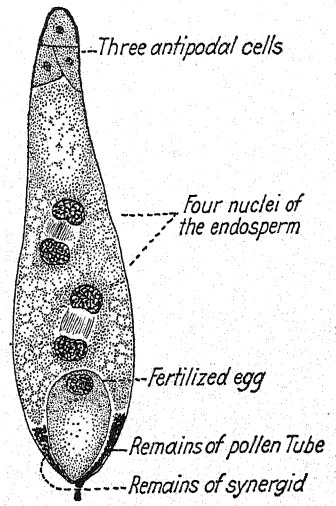


FIG. 310.—Embryo sac of Lily shortly after fertilization of the egg. There are four nuclei in the endosperm and the egg has not yet divided. × 185.

The early development of the young embryo is very regular, in many plants almost geometrical. The embryo of the Shepherd's Purse is one of the most regular, and much can be seen by dissecting the embryos out of young seeds with needles; but sections, well cut and stained, are easier to study (Fig. 311).

The fertilized egg lengthens and then begins to divide, forming a filament of several cells (Fig. 311*A*). The top cell of the filament

then divides lengthwise (Fig. 311*B*). These two cells at the top will produce the cotyledons, leaves, stem, and most of the root of the new plant.

A cross-wall now appears in the two top cells (Fig. 311*C*). This is important, because the cells below the cross-wall will produce the root; and the cells above will produce the cotyledons, stem, and leaves.

A protective layer of cells appears next at the outside and remains only one cell thick, although it keeps dividing so as to make enough cells to cover the whole surface of the plant (Fig. 311*D*).

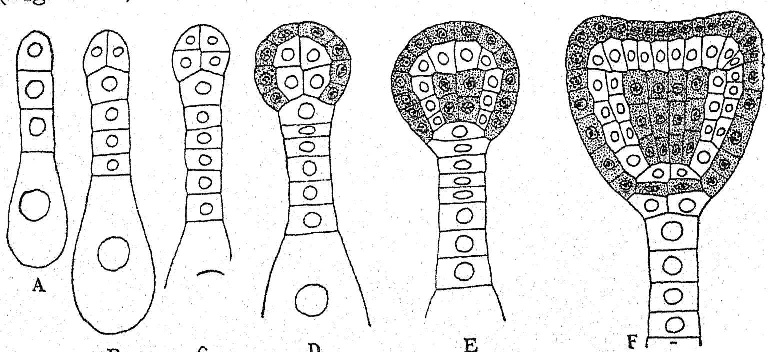


FIG. 311.—Shepherd's Purse (*Capsella bursa-pastoris*). Stages in the development of the embryo. In *D*, the shaded cells (dermatogen) are to produce only epidermis; in *E*, the shaded cells in the center are to produce the vascular system of the root; in *F*, the dermatogen is complete and the cotyledons are just beginning to appear. The vascular system of the stem is not yet recognizable. × 520.

The next divisions in the root portion separate the part which is to become the woody cylinder from the part which is to be cortex (Fig. 311*E*).

A later stage is shown in Fig. 311*F*, in which the two cotyledons are just beginning to appear as rounded elevations, like those which are to become leaves, branches, sepals, petals, stamens, or carpels. They are all very similar when they are young. This figure shows that the root has developed much faster than the stem; but when the seed germinates and the root becomes established in the soil, the stem develops faster. A young seed with its embryo, endosperm, and various structures for nutrition and protection is very complicated (Fig. 312).

Leaves do not appear in the Shepherd's Purse until the seed germinates; but in many plants, like the Bean, the first leaves are well developed in the ripe seed.

The Dicotyls received their name because their embryos have two cotyledons. The Monocotyls have only one cotyledon. In

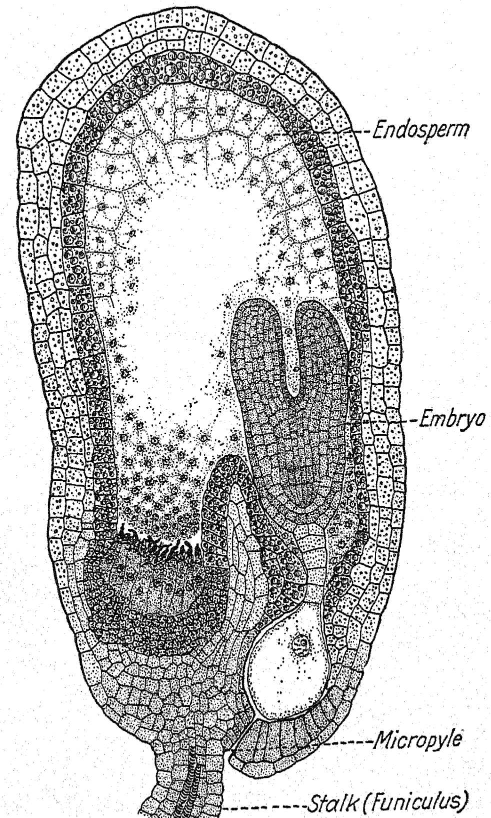


FIG. 312.—Shepherd's Purse (*Capsella bursa-pastoris*). Ovule (megasporangium) with embryo and endosperm. × 60.

the Dicotyls the stem tip is between the two cotyledons; in the Monocotyls the single cotyledon seems to be at the tip of the embryo with the stem tip at the side (Fig. 313). But there are exceptions. Some Dicotyls have only one cotyledon and some Monocotyls have two; and in many Monocotyls there is one

good cotyledon and a weakly developed one. This is one of the reasons why many botanists think the Monocotyls have come from the Dicotyls.

When the endosperm nucleus divides, in the Shepherd's Purse and in most Angiosperms, a wall does not come in between the two resulting nuclei; but one nuclear division follows another, without any walls, until there may be hundreds of nuclei lying free in one mass of protoplasm. Then walls come in and the whole space becomes filled with cells, each with its own nucleus. In Fig. 312 walls are being formed at the top of the endosperm; but, at the bottom, many of the nuclei are still free.

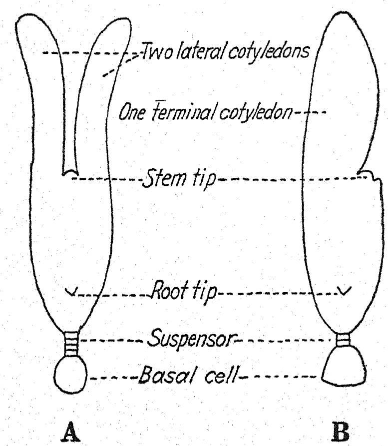


FIG. 313.—Diagrams of embryos. *A*, Dicotyl; *B*, Monocotyl.

If an embryo sac is very small, or is long and slender, the endosperm may have walls from the start.

In many plants, like the Bean, the endosperm is formed but is absorbed by the cotyledons, so that in the ripe seed there is no endosperm. A few plants with very small seeds, like the Orchids, have no endosperm at all.

Seed and Seedling.—The seed occupies an extremely important place in the life history of the plant. The object of the flower, with all the devices for attracting insects to insure pollination, is, finally, to produce a seed.

The essential part of a seed is the new plant—the embryo—contained within it. The endosperm is to nourish the embryo, and the seed coats are to protect both endosperm and embryo.

Most seeds, when their embryos are mature, become very dry, so that they are not in much danger from freezing; and their seed coats protect them against other unfavorable conditions.

The seed develops from the ovule, the embryo coming from the egg in the embryo sac and the endosperm from the endosperm nucleus with the protoplasm surrounding it. The seed coats

come, generally, from the integuments. Since the development is continuous from fertilization to the ripe seed, it seems best to begin calling the ovule a seed as soon as fertilization takes place.

From the standpoint of alternation of generations, there are three generations in a seed: the embryo, which is a young sporophyte; the endosperm, which had better be regarded as a gametophyte; and the seed coats, which belong to the old sporophyte. The three generations are shown in Fig. 314 and also in Fig. 319.

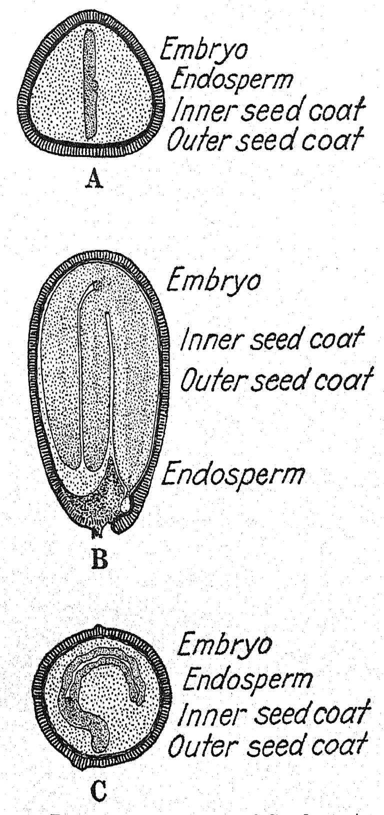


FIG. 314.—Sections of Seeds. *A*, *Iris pseudacorus*; *B*, Shepherd's Purse (Capsella bursa-pastoris); *C*, Basswood (*Tilia americana*). The embryo, at the center, is more deeply shaded; the endosperm lightly dotted; the inner seed coat, black; the outer seed coat, shaded with lines. × 3.

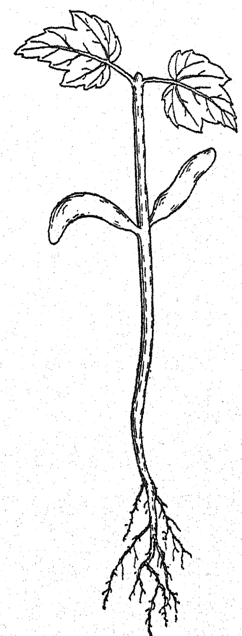


FIG. 315.—Seedling of Red Maple (*Acer rubrum*).

In some seeds the embryo is straight and is surrounded by abundant endosperm, as in the *Iris;* in some the embryo is folded, as in the Shepherd's Purse; and in some, it is coiled, as in the Basswood, Pigweed, Goosefoot, and many members of the Goosefoot and Amaranth Families (Fig. 314).

When the seed germinates, the root grows down into the soil and the stem grows up in the opposite direction. The cotyledons supply food for a little while and then dry up. As soon as the young plant breaks out from the seed, it is called a seedling (Fig. 315). Its first leaves are often quite different from those of the mature plant.

The Fruit.—Not only does fertilization start the egg on a course of development which continues until it becomes a mature plant, but, in some way, associated structures are stimulated so that they grow immensely, sometimes reaching hundreds or even thousands of times the size they had before fertilization took place. The Pumpkin, Squash, Watermelon, Apple, Orange, Grapefruit, Bean, and Coconut are familiar examples. In nature the decaying fruits enrich the soil so that it becomes well suited for the germination of the seeds and the growth of the young plants.

A Comparison of the Life Histories of Gymnosperms and Angiosperms.—A comparison of the life histories of a true Fern and *Selaginella*, a Pine and an Angiosperm will make all of these easier to understand; for they have some features in common, while in others they are different. The stages in which they are most alike are the early ones.

When the first Ferns appeared, there were no Gymnosperms or Angiosperms. These came later and, almost certainly, are modified descendants of the Ferns. Botanists believe this is the reason why the Ferns and Gymnosperms and Angiosperms are so much alike in the early stages of their life histories.

A careful study of Figs. 316 to 320 will be better than a long description; but a brief review of some phases of life histories will make it easier to interpret the illustrations.

The Bracken Fern will represent Ferns which have only one kind of sporangium with one kind of spore in it; and *Selaginella* will represent those which have two kinds of sporangia with two kinds of spores—microspores and megaspores.

In the Bracken Fern the spore mother cell produces four spores. When the spore germinates, the gametophyte breaks out from the spore, gets green, and bears antheridia, which produce sperms, and archegonia which produce eggs. A sperm fertilizes an egg which develops into a new plant.

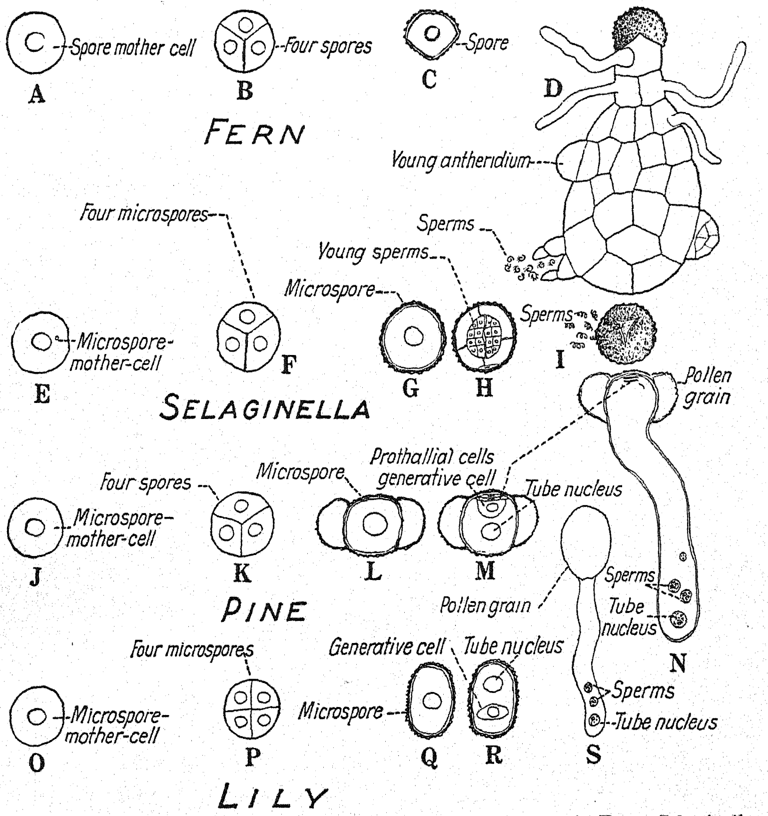


FIG. 316.—Diagrams comparing the development of sperms in Fern, *Selaginella*, Pine, and Lily.

In *Selaginella* the microspore mother cell produces four microspores, but, when a microspore germinates, the male gametophyte does not break out from the spore and get green; it stays inside, is colorless, and produces one or two antheridia, which discharge their sperms through a crack in the spore coats.

In the Pine the microspore mother cell also forms four microspores. When the microspore germinates, the male gametophyte stays inside, as in *Selaginella*. Two small cells are formed at one end of the microspore. They correspond to the whole green gametophyte, or *prothallium*, of the Bracken Fern before the formation of antheridia and, on that account, are called *prothallial cells* (Fig. 316*M*, *N*). The rest of the microspore is a young antheridium. The antheridium divides once before shedding, forming a small *generative cell* and a larger *tube cell* (Fig. 316*M*). In this condition the microspore (pollen grain) is shed. In the Fir there is one more division before shedding; but in both the Pine and Fir, as the pollen tube nears the egg, two sperms are formed (Fig. 316*N*). Both of them enter the egg and one unites with the egg nucleus; the other usually dies. The fertilized egg is now the first cell of a new sporophyte.

In the Angiosperms the microspore mother cell starts in the same way, producing four microspores; but there are no prothallial cells. The whole microspore is the first cell of an antheridium. Just before the microspore (pollen grain) is shed, its nucleus divides, forming a tube nucleus and a generative nucleus. If fertilization is to follow soon after the pollen is shed, the generative nucleus divides and forms two sperm nuclei before the shedding; but if fertilization is to be delayed several days or weeks, the division of the generative cell takes place in the pollen tube. In both cases one sperm nucleus unites with the egg nucleus, and the other unites with the endosperm nucleus. The fertilized egg is the first cell of a new sporophyte plant.

The megaspore series, leading to the formation of eggs, also show similarities, especially in the early stages (Fig. 317).

In *Selaginella* the megaspore mother cell produces four megaspores. Each megaspore, when it germinates, produces many nuclei lying free in the protoplasm; then cell walls come in, and a few eggs are formed at the top of the gametophyte. By this time the megaspore has fallen out from the megasporangium and is lying on the ground, where sperms enter the necks of the archegonia and fertilize the eggs.

In *Pinus* the megaspore mother cell produces four megaspores arranged in a row. One megaspore enlarges and the other three are absorbed by the enlarging megaspore, which behaves like that

of *Selaginella*, producing a large number of nuclei without any cell walls; then walls come in and a few eggs are formed at the top (Fig. 317). In some very important features *Selaginella* and *Pinus* are different. In *Selaginella* the megaspore has a thick spore coat and falls out from the megasporangium, usually before

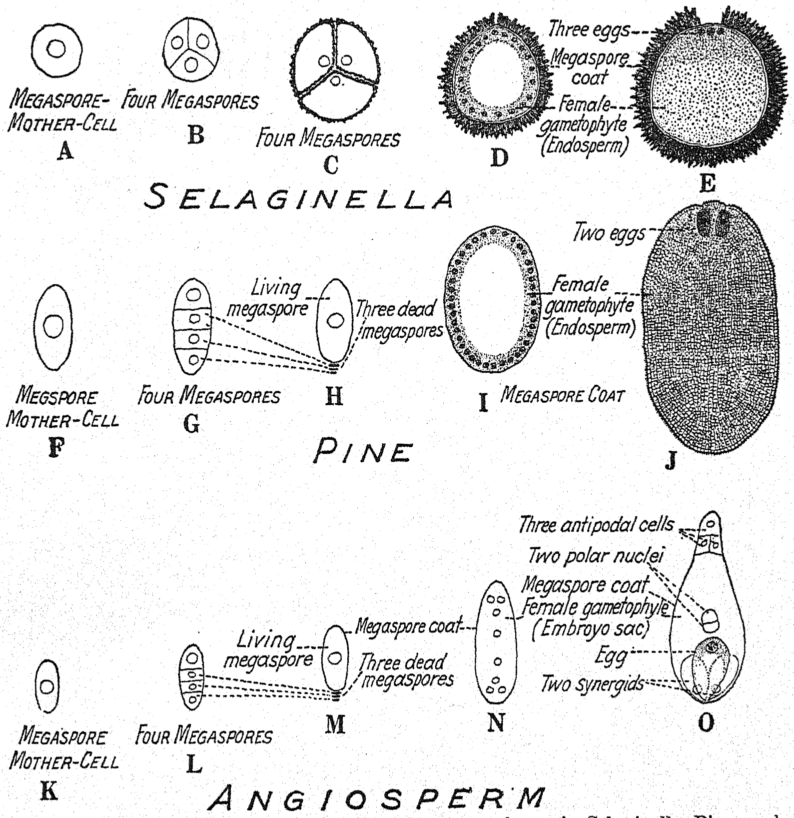


FIG. 317.—Diagram comparing the development of eggs in *Selaginella*, Pine, and an Angiosperm.

the eggs are formed. In the Pine the megaspore has a thin spore coat and *never* falls out from the megasporangium; it always stays inside, even when the seed germinates.

In the Angiosperms the megaspore mother cell forms a row of four megaspores, as in the Pine; then one of the megaspores grows large, as it absorbs the other three. Soon there are nuclei lying

free in the protoplasm, but, instead of the large number found in the Pine, there are almost always just eight, one of which forms the *egg*, two form the *synergids*, three form the *antipodal cells*, and the other two, the *polar nuclei*, unite to form the *endosperm nucleus*. So, the female gametophyte in the Angiosperms is

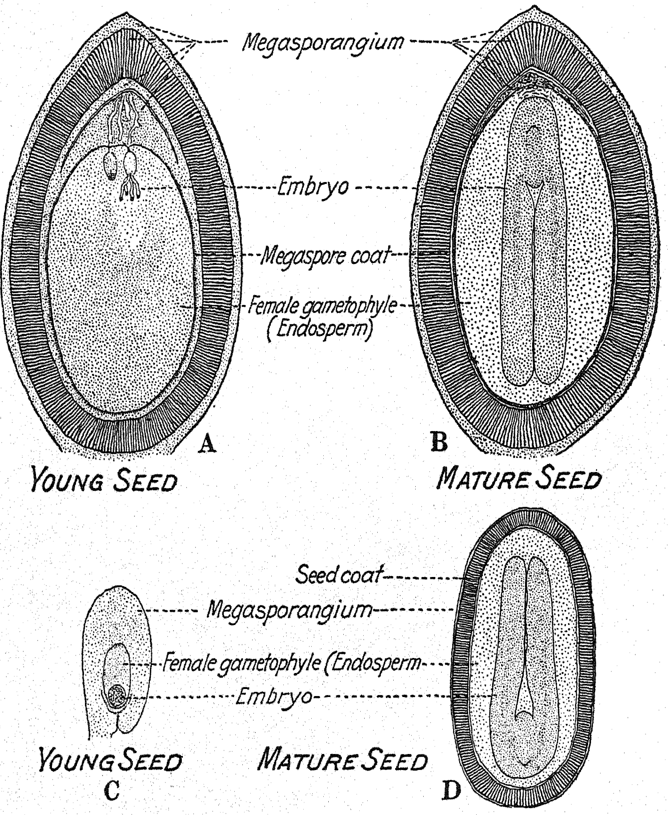


FIG. 318.—Diagrams comparing the seeds of Gymnosperms and Angiosperms. *A* and *B*, Gymnosperms; *C* and *D*, Angiosperms.

very much reduced (Fig. 317*O*). It is microscopic in size. While it has a spore coat, the coat is only an ordinary thin cell wall. Spores which are to be shed have thick spore coats; but, as megaspores began to be retained inside the megasporangium, the spore coats became thinner, as in the Pine and, finally, very thin, as in the Angiosperms.

In the development of the embryo the Gymnosperms and Angiosperms show the most differences in the early stages and become more alike in later stages.

In the Pine the fertilized egg soon has four nuclei lying free in the protoplasm. They sink to the bottom of the egg and divide, forming cell walls; then two more divisions result in forming four tiers of cells with four cells in a tier. The bottom cell of each tier makes an embryo, so that four embryos come from each fertilized egg. Several eggs may be fertilized and many embryos start to develop; but one of them absorbs all the rest

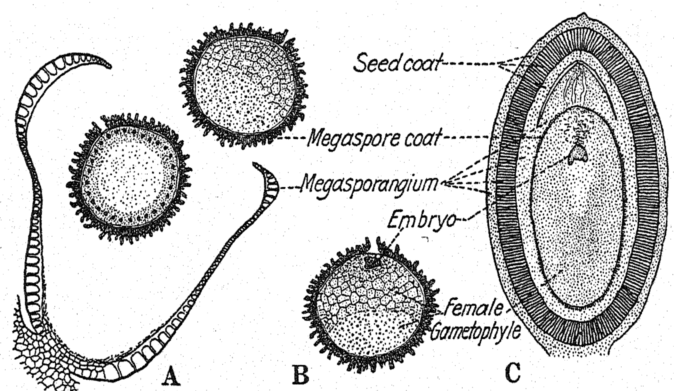


FIG. 319.—Diagrams contrasting a seed with nearest approach to the seed habit. *A* and *B*, *Selaginella*; *C*, *Pinus*.

and the ripe seed almost always contains only one embryo (Fig. 318*A*, *B*). The embryo of the Pine has several cotyledons, but the White Cedar and many other Gymnosperms have only two. The embryo is surrounded by endosperm and outside the endosperm are the seed coats.

In the Angiosperms there is only one egg, and it produces only one embryo. It is surrounded by endosperm which, in many cases, is absorbed by the young embryo, so that the mature seed does not seem to have any endosperm. Outside the endosperm are the seed coats. The embryo in the Dicotyls has two cotyledons, but in the Monocotyls there is only one (Fig. 313, 318).

The differences between a seed and the corresponding structures in the Ferns which have led up to the true seeds is shown in Fig. 319.

In the common Ferns, like the Bracken Fern, there is only one kind of spore and, when it germinates, the gametophyte at once breaks out, gets green, and produces sperms and eggs. A sperm fertilizes an egg and a new plant is started (Fig. 252).

In *Selaginella* there are two kinds of spores—microspores and megaspores—which are shed as in the Bracken Fern. They fall on the ground, and their gametophytes, developing inside the

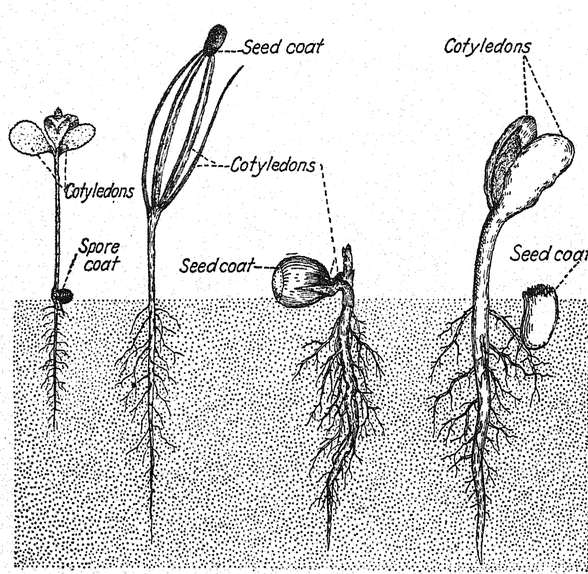


FIG. 320.—*A*, sporeling of *Selaginella; B*, seedling of Pine; *C*, seedling of Oak; *D*, seedling of Bean.

spores, do not get green; but a sperm fertilizes an egg, which develops into a new plant. In *Selaginella* the embryo has two cotyledons (Fig. 320).

The true seed, when ripe, is a megasporangium containing a megaspore which has germinated, producing a female gametophyte with an egg; and the egg has been fertilized and has developed into an embryo. This is seen more clearly in the Pine, where the megaspore coat is easily recognized in the ripe seed (Fig. 318).

The closest approach to a seed in any plant below the Seed Plants is in *Selaginella*. The megaspore germinates inside the

sporangium but falls out, and the young sporeling becomes established in the soil, after the megaspore has fallen out from the megasporangium. If the megaspore should stay inside the megasporangium, so that the root, stem, and leaf would break out from the megasporangium, leaving the megaspore inside, *Selaginella* would be a Seed Plant.

The lowest Seed Plants, now known only as fossils, looked like Ferns; and there is scarcely any doubt that in some of them the megaspores sometimes stayed inside the megasporangium and sometimes fell out. In such cases it would be hard to draw a line between Ferns and Seed Plants.

The sporeling of a Fern, of *Selaginella*, of a Pine and of the Oak, Bean, and Corn show the differences in behavior between the spores of Pteridophytes and the seeds of the Seed Plants (Fig. 320).

In studying a series of forms from the Liverworts up to the Seed Plants one cannot help noticing the decreasing size of the gametophyte and the increasing size of the sporophyte. In Liverworts, like *Marchantia*, the gametophyte is large, green, and independent, while the sporophyte is almost microscopic and is parasitic upon the gametophyte.

In the Mosses the two generations are about equal in size, and both are green; but the sporophyte is always parasitic upon the gametophyte.

In the true Ferns the gametophyte is still green and independent, but it is very small. The sporophyte is parasitic on the gametophyte for a while but soon becomes independent and may reach a great size, as in the Tree Ferns.

In *Selaginella* the gametophytes have become microscopic, colorless, and entirely parasitic upon the sporophyte.

In the Pine the gametophyte is not so small, but it is colorless and entirely parasitic upon the sporophyte, which reaches such an immense size that there is much more difference between the two generations than in *Selaginella*.

In the Angiosperms the gametophytes are microscopic, colorless, and entirely parasitic upon the sporophyte. The sporophytes are the familiar herbs, shrubs, and trees.

The reduction of the gametophyte and the rise of the sporophyte can be illustrated by a diagram (Fig. 321).

The Economic Value of Seed Plants.—The U. S. Department of Agriculture can tell the value of the Wheat, Oat, or Corn crop for any year; they know the number of bushels of Potatoes; they know all about the Celery, Radishes, Onions, Apples, Pears, Peaches, Oranges, Lemons, Grapes, and the rest. The Bureau of Forestry knows how much lumber has been cut and how much it was worth; and they know what steps are being taken to keep up the supply. The Federal Horticultural Board not only knows about flowers and decorative plants, but also watches everything from Pines to Pansies, keeping out diseased plants and other undesirables.

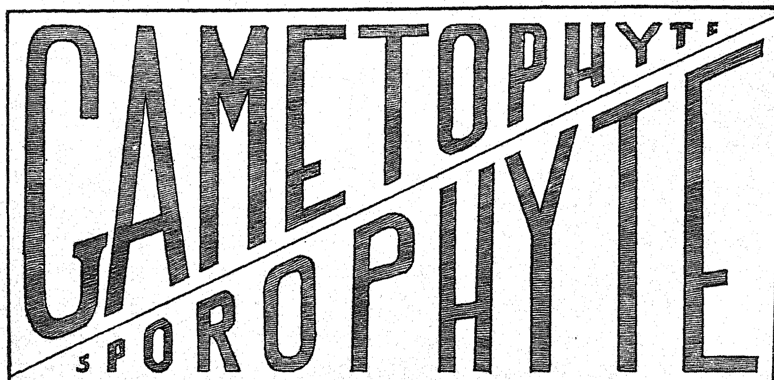


FIG. 321.—Diagram indicating the reduction of the gametophyte and the development of the sporophyte.

It is not hard to find the money value of any Seed Plants grown in the United States; but their greatest value could not be estimated by finding out how many dollars each crop was worth. We need our bread, our oat meal, and our corn flakes; and we should miss our pie and cake. Without the Grass, the supply of milk, steak, and chops would be cut off. Without the Seed Plants all the higher animal life, including ourselves, would soon come to an end.

Most of our cultivated plants are very different in their wild condition. No one but a trained botanist would recognize, as a Cabbage, the wild plant from which our modern Cabbage has come.

Corn grown in Peru and Mexico, with small ears, doubtless looks more like the ancestral plant than the fine Corn, with large

ears, grown in the United States. But even the ancient Peruvians and Mexicans had cultivated and improved Corn for a long time. Modern methods, based upon scientific knowledge of plants, make more progress in a few years than the ancients were able to make in centuries.

Apples could not have been very good in Caesar's time, or the Roman poets would have written odes to the Apple. The Golden Apples of the Hesperides, which Hercules got for Eurystheus, and the Apple of Discord, which Venus managed to secure, were probably Oranges. Apples are better now than they were 25 years ago, and most of the Apples on the market today have been developed since the Civil War.

The small wild Grape, found now in the forests and along streams, has been developed into some of our finest Grapes since the Pilgrim Fathers landed at Plymouth Rock.

Trained horticulturists are quick to recognize desirable variations, and they know how to keep them by grafting, cuttings, budding, and other forms of vegetative propagation. Selecting the best types and crossing plants so as to combine desirable qualities is making vast improvement. Wheat has been developed to fit the conditions of the northern, middle, and southern states. Many crops have been developed to fit the kind of regions where they are to be grown. The same variety of Cabbage might not be suited to the northern, middle, and southern states; but scientific experiment determines what varieties are best for each locality. Improvement in Seed Plants is adding greatly to their value. A very well-trained botanist, who is still a specialist in Orange culture, once said that a hard problem had been given him to work out. He should make an Orange as large as the best Navel Orange; juicy and sweet, with the finest flavor; a skin as thin as that of a Tangerine and peeling off as easily, but protecting against drying up as well as the thick tight skins; the segments of the Orange must come apart easily; there must be no seeds; and the plant must be hardy up to the coldest limit of Orange growing. The most interesting thing about the problem is that the man did not regard it as a joke but as a practical problem, capable of solution, perhaps not in one man's lifetime but, nevertheless, capable of solution.

Improvements in Seed Plants is not always direct. An investigation of the microscopic features of fertilization in the Lily, published in Russia in 1898, has increased the yield of Corn, Wheat, and other crops all over the world, because it enabled investigators to experiment definitely instead of blindly. It seems likely that a thorough scientific knowledge of plants will bring about the greatest improvement in the shortest time and thus keep increasing their value.

Physiology of Seed Plants.—Plant physiologists have confined their attention almost entirely to Seed Plants. In Part I some of the most important functions of plants have been noted, like the movements of liquids, giving off oxygen, formation of starch, and relations to light, temperature, and moisture.

For an ideal study of the physiology of plants one would need to combine a thorough knowledge of the structure and development of plants with a study of their behavior.

A study of the structure and development of a leaf, from the time it appears as a small rounded elevation near the tip of the stem up to the mature leaf, belongs to morphology; but what causes the rounded elevation to start and what causes it to develop into a mature leaf belongs to physiology. The whole problem of growth belongs, largely, to physiology; and growth depends upon getting crude food materials, manufacturing them into usable foods, and distributing foods to places where they are needed. To study the nutrition of a plant one needs to know chemistry.

The movements of leaves and the twining of stems and tendrils are problems of physiology. It is for the physiologist to find out why roots grow down and stems grow up; why stems turn toward the light and roots turn away from it. The morphologist studies the various stages in the life history of a plant; the physiologist should find out why the plant goes from one stage to another until the life history is complete. If morphologists knew more physiology and physiologists knew more morphology, many problems might be solved by experiment.

Ecology.—Ecology is a comparatively new line of botanical study. It is really a study of plants in relation to their surroundings.

The ecologist can classify plants as *Hydrophytes*, plants growing in the water or in wet places, like the Water Lily, Cat Tail, and Blue Flag; as *Mesophytes*, plants growing in medium places, neither very wet nor very dry, like the Oak, Beech, and Maple; and as *Xerophytes*, plants growing in very dry places, like the Cactus, Century Plant, and Mesquite.

An important part of ecology deals with *succession*. If one were to make a map of all the plants of a region and the same region should be examined a few years later, it would be found that some of the first plants had disappeared and that others had taken their places. When a bare volcanic island is raised above the water, the first plants to appear on it are Algae and then Lichens. As these decay, they fill crevices in the rocks and form a little soil in which higher plants can grow and, gradually, a higher type of vegetation is developed. This is an example of *succession.*

Even after the higher type of vegetation has appeared, changes may occur. If seedlings of some plants cannot develop in the shade, those plants cannot replace themselves, and, when they die, others whose seedlings can grow in the shade will take their places. A forest in which there are no young trees of the same kind coming on cannot maintain itself. It will be replaced by other types.

In many regions there are forests of Oak, Beech, and Maple with many young trees coming on as the older trees die. Since such a forest can maintain itself indefinitely, it is called a *climax formation.* The study of successions is a very important part of ecology.

Plant geography, dealing with the distribution of plants as they are now and as they were in geological times, is another phase of ecology.

Ecological anatomy is another interesting phase of ecology. A comparison of the structure of the leaves of Hydrophytes, Mesophytes, and Xerophytes belongs to ecological anatomy. A comparison of the conducting systems of plants growing in wet, medium, and dry places also belongs here; and here also the study of adaptations, like the various adaptations of flowers for insect pollination, the peculiar structures of insectivorous plants, hairy or spiny structures, and structures to prevent the loss of water. The arrangement of leaves in mosaic

patterns to secure the best light relations is an ecological reaction.

It is evident that morphology, physiology, and ecology are not sharply separated from each other but overlap, so that botany cannot be subdivided into distinct parts with no relation to each other.

Pathology.—Pathology deals with the diseases of plants and, since the Seed Plants are the only ones whose diseases have much practical importance, pathologists have confined their attention, almost exclusively, to this group. But so many diseases are caused by Bacteria and Fungi that a considerable part of pathology consists in studies of life histories of the Fungi which cause diseases. Such a study shows in what part of the life history the Fungus does the damage and also shows in what part of its life history it may be most easily destroyed.

Rusts do immense damage to Wheat and Oats, Smuts cause great losses in Corn, Club Root causes losses in Cabbages, and nearly every one of the plants upon which we depend for food is subject to one disease or another.

Fruits and vegetables often leave the farm in apparently perfect condition but really slightly infected. The disease spreads during transportation and there is a great loss. Scientific experiment has shown how one disease and another can be kept down by just the right temperature during transportation. Some diseases can be kept down by taking more care in picking and packing the fruit.

Some diseases are controlled by disinfecting the seed; some by spraying; the Wheat Rust can be kept down, to some extent, by removing Barberry bushes; and Apple Rust can be avoided by cutting down all the Juniper trees in the vicinity. But the most effective way of avoiding all diseases is to secure immune plants and propagate from them, rather than attempt to cure a disease already started.

The U. S. Department of Agriculture has hundreds of men and women working on the diseases of plants, and they are preventing millions of dollars of loss every year. The U. S. Bureau of Markets is becoming very useful. By its experiments it is lessening losses during transportation; by its field studies, it is showing how to prepare various things for transportation; and, by its inspection service, it protects the shipper who was often

told that his shipments arrived in poor condition, when they were really very good.

The scientific study of plant diseases and their control is progressing so rapidly that losses in some of the most important products are becoming comparatively small.

Classification of Seed Plants.—The earliest study of seed plants was devoted to their medical properties, but an attempt to classify them came next. An early classification made three groups—herbs, shrubs, and trees. The early classifications were artificial, because no one believed that any plants were related to each other. Linnaeus divided the Seed Plants into families according to the number of stamens, so that plants with one stamen went into one family, plants with two stamens went into another, and so on. Then botanists began to place together those plants which looked as if they were related to each other; and so groups were formed like Rose Family, Pea Family, Mustard Family, Mint Family, Sunflower Family, Grass Family, Lily Family, Orchid Family, and many others.

Then those families with two cotyledons in the seedling were put into one group, called Dicotyls; and those with one cotyledon were put into another group, called Monocotyls. Those Dicotyls with no petals, or with several separate petals, were placed together; and those with the corolla in one piece, like the Morning Glory, were placed in another.

During the past 50 years it has become evident that the Dicotyls with no petals or with several separate petals are the main stock, and that the Monocotyls and also those Dicotyls which have the corolla in one piece have come from this main stock.

The names of plants can be found by means of keys. A well-known key to the Dicotyls starts as follows:

- Corolla none
- Both calyx and corolla present
  - Corolla of separate petals
  - Petals more or less united
    - Stamens more numerous than the lobes of the corolla
    - Stamens not more numerous than the corolla lobes

Such a key is really a short description and, by following it, one finally comes to the *family*, *genus*, and *species*. The genus

and species together make up the name of the plant, as *Populus tremuloides* (the Aspen Poplar). *Populus* is the genus name and it applies to all Poplars; *tremuloides* is the specific name and it applies only to the Aspen Poplar. *Populus balsamifera* is the Balsam Poplar, and *Populus alba* is the White, or Silver Leaved Poplar.

Gray's famous manual covers the region from the Atlantic to the Mississippi River and from Canada to Mason and Dixon's Line. There are similar manuals for the southern and the western states, with special manuals for Texas and the Rocky Mountains. Besides, there are manuals or "local floras" for limited regions.

A student who has studied this book should be able to find out the names of most of the wild plants of his vicinity. Some plants are sure to be difficult, especially the Goldenrods, Asters, and Hawthorns. Usually, it will not be difficult to find the genus; but, when a genus has many species, some of them are likely to be hard or uncertain. But, on the whole, the student will be surprised to find how easily he can use a manual and find out the names of the wild plants of his neighborhood. Using a manual will increase one's knowledge of plants and will improve the power of observation.

CHAPTER XVIII

LABORATORY METHODS

Any study of science, without laboratory work, is dead.

Living material should be brought into the laboratory whenever possible. A greenhouse and several small aquaria are very desirable, but usually they are not available. Gallon battery jars will serve as small aquaria. A teacher in a large high school once had a small greenhouse built in his laboratory. It was 6 by 8 feet and 7 feet high. It was really a big box with windows for the sides and top. Nearly everything was raised in pots. A few battery-jar aquaria on the floor of the greenhouse not only kept up a supply of Algae but also kept the air from becoming too dry. With this equipment he furnished many types in sufficient quantity for classes of more than one hundred students.

Most of the material needed for class use must be preserved. The most generally useful preservative is a mixture of commercial formalin, acetic acid, and water, about 5 parts of formalin and 1 part of acetic acid to 94 parts of water. Ordinary glass fruit cans are good containers. Material can be left in this solution until it is needed for use. It should then be rinsed well in water, because formalin is irritating to the eyes and skin.

TEMPORARY PREPARATIONS

Small forms, like the filamentous Algae and Fungi, spores and pollen grains, starch grains, and even things as large as fern prothallia, can be mounted in a drop of water and examined fresh or from preserved material. In such cases, place a little of the material on a slide, add a small drop of water, and put on a cover glass.

Some things can be dissected with needles and some can be crushed a little by tapping on the cover glass with a pencil. Even when permanent mounts are to be made, such a study of the living material is very desirable. No one can make a permanent mount of a swimming zoospore or the flowing of protoplasm.

Thin sections of stems, leaves, roots, and other things can be cut with a safety razor blade and examined fresh. This shows the natural colors, especially the chlorophyll.

The value of a study of living material cannot be overemphasized; but material fixed and stained by modern methods shows some structures clearly which can be seen only dimly in living material. Making permanent preparations is a fascinating study, and one learns much about plants as he makes the slides.

PERMANENT PREPARATIONS

It is not difficult to make permanent preparations which can be used repeatedly. The directions may look rather complicated, but they will not seem so hard after a few slides have been made.

Reagents.—Reagents and apparatus are not very expensive. Many teachers may find it harder to get the necessary time than to get their schools to furnish the money. The following are the necessary reagents in sufficient quantities to make about one thousand slides:

Commercial formalin (take it from the stock used for preserved material)

Acetic acid	100 c.c.
Alcohol, 95 per cent	2 liters
Alcohol, absolute	1 liter
Xylol	1 liter
Safranin	10 grams
Gentian violet	10 grams
Haematoxylin	5 grams
Iron alum (ammonia sulphate of iron)	20 grams
Eosin	10 grams
Glycerine	1 liter
Clove oil	100 c.c.
Venice turpentine	1 pound
Balsam	100 c.c.
Paraffin or parowax	5 pounds
Slides and covers	
Safety razor blades	
Solid watch crystals (the kind called *minots*)	2 dozen
1 sliding microtome	

All of these reagents are easily obtained except the alcohol. Wood alcohol will do for all the grades except absolute alcohol. Acetone is a fairly good substitute for all the grades of alcohol except the absolute alcohol. Synthol (furnished by the Bausch and Lomb Optical Co.) is another substitute. Educational institutions can get alcohol at reasonable rates, but there is some red tape.

Various grades of alcohol, below 95 per cent alcohol, are made by mixing 95 per cent alcohol and water as follows:

95	95	95	95	95	95
10	20	35	50	70	85
—	—	—	—	—	—
85	75	60	45	25	10

In the first column, subtract 10 from 95; the result, 85 is the number of cubic centimeters of water which must be added to 10 c.c. of 95 per cent alcohol to obtain 10 per cent alcohol. The mixture contains 95 c.c. of 10 per cent alcohol.

In the second column, 75 c.c. of water added to 20 c.c. of 95 per cent alcohol gives 95 c.c. of 20 per cent alcohol. In the last column, 10 c.c. of water added to 85 c.c. of 95 per cent alcohol, gives 95 c.c. of 85 per cent alcohol. Any grade, below 95 per cent, can be made in the same way.

Grades lower than 20 per cent alcohol can be made, approximately, from 20 per cent alcohol. For 10 per cent alcohol, mix 20 per cent alcohol and water, half and half; and for 5 per cent alcohol mix the 10 per cent alcohol and water, half and half.

Grades of xylol can be made in the same way, but a long series is not necessary for this work: four grades, 25, 50, and 75 per cent and pure xylol will be sufficient. Make the 25 per cent xylol by mixing one part pure xylol with three parts of absolute alcohol; for 50 per cent xylol, mix pure xylol and absolute alcohol, half and half; and for 75 per cent xylol, mix three parts of pure xylol and one part of absolute alcohol.

The other reagents are made as follows:

Safranin: Dissolve 1 gram in 100 c.c. of water. For an alcoholic solution, dissolve 1 gram in 100 c.c. of 95 per cent alcohol. A very good safranin is made by mixing these two, half and half, so as to get a 50 per cent alcoholic solution.

Gentian Violet: Dissolve 1 gram in 100 c.c. of water.

Eosin: Dissolve 1 gram in 100 c.c. of water.

Haidenhain's Haematoxylin: Dissolve 1 gram in 200 c.c. of water.

This stain needs to "ripen." When the color becomes a rich purplish red, the stain is ready for use. This may take 3 weeks. Unfortunately, the stain remains at its best only 3 or 4 weeks. This stain can also be made by dissolving 2 grams of haematoxylin in 6 c.c. of absolute alcohol. It will ripen in about 3 weeks and will keep for a year. When wanted for use, take 1 c.c. of the alcoholic solution and mix with 50 c.c. of water.

Iron Alum (ammonia sulphate of iron): Dissolve 10 grams in 500 c.c. of water. It will keep for a year if not exposed to bright light.

Glycerine: A 10 per cent solution is made by mixing 10 c.c. glycerine with 90 c.c. of water.

Venice Turpentine: A 10 per cent solution is made by mixing 10 c.c. of Venice turpentine with 90 c.c. of absolute alcohol. The best way to make this is to get a *perfectly dry* bottle with the metric scale on the glass, pour in the Venice turpentine and add the absolute alcohol. Cork it immediately and shake occasionally until the two are mixed. The least bit of moisture ruins the 10 per cent solution; but pure Venice turpentine can be handled like Canada Balsam.

Balsam, clove oil, and paraffin are used without mixing. Any scales which will weigh half a gram rather accurately are sufficient.

In learning to make permanent stained preparations which require so many reagents, it is better to begin with those which present the fewest difficulties in technique, rather than to take the Algae, Fungi, and other groups in sequence. Free-hand sections, glycerine and Venice turpentine method, and the paraffin method will furnish an introduction to the whole subject of preparing plant material for microscopic study.

Free-hand Sections.—Take a stem of *Geranium*, Basswood, or any other plant which is not too hard. Cut off a piece about 2 inches long; hold it firmly with the thumb and finger of the left hand; take a safety razor blade in the right hand, steadying the blade on the first finger of the left hand, and cut sections as thin as you can. With a little practice you should soon be able to cut thin even sections. Put the sections into 95 per cent alcohol, in a minot watch glass, and leave them there for half an hour. It will do no harm to leave them over night, if the dish is covered so that the alcohol will not evaporate. Then transfer them to 85, 70, and 50 per cent alcohol, about 5 minutes in each. If the sections look greenish in the 50 per cent alcohol, they must stay there until the chlorophyll, which causes the greenish color, has dissolved.

From the 50 per cent alcohol transfer the sections to the 50 per cent alcoholic safranin, and leave them there for 6 hours; they may remain in the stain over night or even for a couple of days. Rinse in 50 per cent alcohol until the thin walls lose the sharp red color and become pink, while the thick-walled woody cells are still bright red. If this takes more than 10 or 15 minutes, a *very* small drop of hydrochloric acid added to the 50 per cent alcohol will hasten the process. Transfer the sections to 35, 20, and 10 per cent alcohol, with about 2 or 3 minutes in each, and then put them into water for 2 or 3 minutes. Stain in gentian violet for 5 or 10 minutes. Rinse in water about 1 minute and then run through a series of alcohols, 35, 50, 70, 85, and 95 per cent, with about 20 seconds in each grade. If the gentian violet washes out, skip the 35 and 50 per cent, or even all of the alcohols except the 95 per cent. Then put the sections in absolute alcohol for 1 minute.

Transfer to clove oil and watch until the gentian violet shows a beautiful violet color. This may take half a minute, but may take five minutes. The woody cell walls and the cuticle should be red and the thin, cellulose walls should be violet.

Transfer from the clove oil to xylol and leave the sections here for a couple of minutes. They may be left for hours, or for months, but keep the dish covered to prevent drying.

If the xylol shows any milky tinge, it is due to water, the worst thing, at this stage, that the histologist has to contend with.

Mix a little absolute alcohol and xylol. If the mixture looks milky, there is water in the absolute alcohol. If the milkiness disappears in a minute or two, there will not be enough water to do much damage. Clove oil will clear from absolute alcohol which is down to 99 or even 98 per cent. From clove oil, sections will go into xylol without any trouble.

After the sections have been in xylol for a few minutes, put one on a slide, add a drop of Canada balsam, and put on a thin cover glass. It is well to pass the cover quickly through a clear flame, like that of a Bunsen burner, or lay it on a hot plate to make sure that there is no moisture. Then let one edge of the cover touch the slide and lower the cover gently, so as not to catch any air bubbles.

The slide is now complete, except that there should be a label pasted on the left end of the slide. *Geranium, cross-section stem*, is enough for the label,

A two or three years old Basswood stem cuts easily. Proceed as with the *Geranium* stem. The thin-walled cells of the pith, the cortex, the cambium, and the sieve cells of the phloem should stain violet; and the woody cells and also the "bast" cells of the phloem should stain red. The bast cells, which are rather thick-walled tracheids, should appear as several red bands in the phloem. This preparation should show the annual rings due to the difference between the spring and autumn wood.

The rhizome of a Fern, especially the Bracken Fern, is easy to cut and makes beautiful sections.

Try White Pine from a well-seasoned board. For the cross-section, take a piece about two inches long and a quarter of an inch square. For the longitudinal radial sections, take a similar piece, parallel with the pith rays; and for the longitudinal tangential sections, take a piece perpendicular to the pith rays, or tangential to the annual rings. These pieces should be at least an inch long, so that they may be held firmly.

Nearly everything will stain red; but the pith rays—except a row or two of cells at the top and bottom—will stain violet.

Leaves, especially thin leaves, are not so easy to cut as stems; but if strips be cut about a quarter of an inch wide and an inch long, a dozen or more strips can be tied together, letting about a quarter of an inch out beyond the string. Then hold the bunch just like a stem and cut across the whole group. Pick out the thin sections and proceed as with the *Geranium* stem sections.

Epidermis of a leaf, stripped off, can be treated like a thin section. The epidermis strips easily from the Onion and from many fleshy plants like Hen and Chickens (*Sedum*). The epidermis does not strip so easily from a Lily, but the stomata are large and the preparations are fine.

With this start, a student can experiment with anything he can cut. Hard stems, like Oak, Maple, and Hickory, are hard to cut, but easy to stain. Things too hard to cut, like Peach stones and Walnut shells, can be sawed into fairly thin sections which can be rubbed down between two hones until they are as thin as the *Geranium* sections. They do not need any staining. Put the section into 95 per cent alcohol for 10 minutes; absolute alcohol, 5 minutes; clove oil, 1 minute; xylol, 5 minutes; and then mount in Canada balsam.

Venice Turpentine Method.—This is a good method for filamentous Algae and Fungi, Moss protonema, Fern prothallia, and numerous objects so small that they can be mounted without sectioning.

Fix in a mixture of formalin and acetic acid—10 c.c. commercial formalin and 5 c.c. acetic acid to 85 c.c. of water. Leave material in the solution for 3 or 4 days. A longer period, even years, does no harm.

Transfer to water, changing the water frequently, for an hour, to wash out all the formalin and acetic acid.

Stain in Haidenhain's iron alum haematoxylin. The steps are as follows:

a. Iron alum (2 per cent), 2 hours; overnight or 24 hours does no harm.

b. Wash in water 30 minutes, changing frequently.

c. Haematoxylin (½ per cent), overnight or 24 hours.

d. Wash in water 30 minutes, changing frequently.

e. Iron alum. This second treatment extracts the stain. Watch the cells under the microscope until the stain looks as you want it. The time will vary from 5 to 30 minutes.

f. Wash in water, changing frequently. If not well washed, the Iron alum will continue to act and the least bit left in will finally draw out all the stain.

g. Transfer to 10 per cent glycerine in a minot or saucer. Leave it exposed to the air—but as little as possible to dust—until the glycerine is as thick as pure glycerine.

At this stage, material can be mounted in pure glycerine. Put a little of the material on the slide in a small drop of glycerine and add a cover. There should be barely enough glycerine to come to the edge of the cover. Such a preparation will last for weeks and it can be made fairly permanent by sealing it. This can be done by dipping a small brush in Canada balsam and painting around the cover so that the balsam will lap a little on the slide and a little on the cover.

If glycerine jelly is available a still better mount can be made. Melt on the slide a small piece of glycerine jelly about half as large as a grain of Wheat. Take a little of the material, dip it on a piece of paper to remove as much of the glycerine as possible, and arrange the material in the melted glycerine jelly. Put on a cover and tap it lightly with a pencil. Even without sealing such a mount may last for years, and, sealed with Canada balsam, it should last indefinitely.

The ideal way, however, is to mount in Venice turpentine. Material which has not been mounted may be carried on as follows:

h. Wash out the glycerine with 95 per cent alcohol. There should be three or four changes, allowing each one to act for half an hour. Material could be washed in less time by making more changes and rocking the dish constantly.

i. Transfer to absolute alcohol and leave the material there for 10 minutes; then change to fresh absolute alcohol and allow it to act for 10 minutes. (These alcohols can be saved and labeled Used Absolute Alcohol. The next time, this can be used for the first absolute alcohol).

j. Transfer to Venice turpentine. This mixture must not be exposed to the air for a single unnecessary second. An exsiccator is necessary for this step. It is easily made. The tin can used for a pound of vacuum coffee will make a good exsiccator. Put an ordinary glass tumbler, upside down, into the can. Around the bottom of the tumbler put some soda lime, or some fused calcium chloride, or a few sticks of calcium hydroxide, and the exsiccator is complete. Put a minot on the tumbler, pour on the 10 per cent Venice turpentine with the material, *quickly*, and add the cover *quickly*.

In three or four days it will be safe to take the cover off. If the Venice turpentine is as thick as molasses, it will be safe to take the material out and mount it.

k. Put a little of the material on a slide with a drop of the thick Venice turpentine and add a cover. The mount will not need to be sealed.

Staining with iron alum haematoxylin may seem difficult at first, but it is really very simple and, when learned, is very reliable, and there should not be many failures.

Staining with eosin is easy and is very good for filamentous Fungi, like the Bread Mold and the Green Molds.

After fixing and washing in water, stain in eosin for 2 days. Wash in water with some acetic acid in it—about 1 c.c. of acetic acid to 100 c.c. of water. Two or three minutes is long enough. Transfer to 10 per cent glycerine. It is not necessary to wash out the acetic acid. Proceed as with material stained in iron alum haematoxylin.

The Paraffin Method.—This is the most precise of all modern methods for obtaining thin sections. It is used for sections of root tips showing dividing nuclei, for anthers with their pollen grains, for megasporangia with their embryo sacs, and for anything where fine details are wanted.

A Lily ovary from a bud about two days before the blossoming time is a good object to start with. Cut it off just above the base of the stamens and just below the style. Then cut it crosswise into three pieces.

a. Fix in a mixture of formalin, 5 parts; acetic acid, 5 parts; and 50 per cent alcohol, 90 parts. Material should be left here for 3 days, but may remain for years.

b. Transfer to 50, 70, 85, and 95 per cent alcohol, 4 hours in each grade; but the material may be left overnight or 24 hours in any of these grades. Then place in absolute alcohol for 2 hours; change the absolute alcohol and allow it to act for 4 hours more. In all the alcohols, only enough to cover the material thoroughly is needed. The alcohols can be used several times, but the absolute alcohol, after using, should be put with the 95 per cent.

c. Transfer to 25, 50, 75 per cent xylol, 4 hours in each: pure xylol, 4 hours or overnight.

d. Add a piece of paraffin or parowax about equal to the volume of the xylol and leave in a warm place—near a radiator—for 24 to 48 hours.

e. Warm gently until all paraffin is melted; pour off the paraffin and put the material in pure melted paraffin in a minot, or some such open dish, and keep the paraffin melted, but do not let it get any warmer than absolutely necessary to keep the paraffin melted.

To keep the paraffin melted, take a box about 8 by 10 inches and 4 inches deep; put in an electric bulb, and use a pane of glass for a cover. Put the shallow dish with the paraffin on the glass top, just near enough the bulb to keep the paraffin melted. Change the paraffin once or twice to make sure that all the xylol has disappeared. About 2 hours in melted paraffin should be sufficient.

Fold a paper box, about 1 by 2 inches and ½ inch deep. Wet it, or take a piece of tissue paper large enough to cover the inside of the box; pour on water so that the tissue paper will stick to the box. Pour off the water and pour in the melted paraffin with the material. Place the box, with the paraffin, on a pan of cold water, and, as soon as the paraffin hardens on top so as to bear the weight of a little water, submerge the box in the cold

water. The material is now *imbedded* in paraffin. The process is called *imbedding*. As soon as the paraffin is hard, it is ready for cutting.

f. To cut thin sections, cut out a block of paraffin with the object imbedded in it and fasten it in a little vise, which can be bought at the 5- and 10-cent store. If you try to hold the paraffin in your hand, it will quickly become too soft to cut.

Brace yourself and rest your arms and hand so as to be as steady as possible, and cut sections as thin as you can.

g. Fasten the sections to a perfectly clean slide. To do this, use a mixture of white egg and glycerine, about 25 c.c. of each, with ½ gram of salicylate of soda to keep out Bacteria. Shake well and filter through cheesecloth.

Take a very small drop of this mixture and smear it evenly over the slide with the finger.

With a pipette (medicine dropper), put several drops of water on the slide and put the sections on the water.

Warm gently to smooth out the sections, but do not let them melt. Drain off as much of the water as possible and let the slides dry overnight or 24 hours, where there is no dust.

For the rest of the stages in making the slides, it is very convenient to have small drinking glasses, just large enough to allow the slide to stand up inside. The glasses should be kept covered. Small squares, cut from a pane of glass, make good covers. Optical companies sell staining jars, called stender dishes, which are very convenient for staining.

One may simply put the various liquids on the slides with pipettes, however, and keep the slides covered in a butter dish to prevent drying up.

It is better to get the glasses and label them as follows: Xylol, Absolute Alcohol, 95 per cent, 85 per cent, 70 per cent, 50 per cent, 35 per cent, and Water. Also have glasses for safranin, gentian violet, iron alum, and haematoxylin.

h. Put the slide in xylol to dissolve off the paraffin; about 5 minutes will be long enough.

i. Transfer to absolute alcohol, 95, 85, 70, and 50 per cent, about 2 minutes in each.

j. Stain in safranin overnight, or 24 hours.

k. Rinse in 50 per cent alcohol until the stain suits you.

l. Rinse in water a few minutes.

m. Stain in gentian violet, 5 or 10 minutes.

n. Wash in water about 1 minute.

o. Holding the slide in a pair of forceps, dip it gently into 50 per cent alcohol, four or five times; then put it into 95 per cent alcohol for a minute. and into absolute alcohol for a minute.

p. Drain off the absolute alcohol; lay the slide down and put on 3 or 4 drops of clove oil. Watch it under the microscope until the stain suits you. Then drain off the clove oil. It can be kept and used again, but do not put it back into the clean clove oil; keep a bottle marked Used Clove Oil.

q. Put the slide into xylol for a minute. It may remain here for hours.

r. Drain off the xylol, add a drop of Canada balsam and a cover, put on a label, and the mount is complete.

The root tip of an Onion is a good object to show dividing nuclei and cells. Put an Onion, about as large as a peach, into a pan of water. When the roots are about half an inch long, cut off the tip, using a piece about one fourth of an inch long. Cut it off and put it into the fixing solution about noon, because nuclei do not divide much in the morning or in the afternoon. Then proceed as with the Lily ovary. The iron alum haematoxylin stain is very good for dividing nuclei.

The paraffin method is very long, but all of the finer modern sections are made in this way.

It is very desirable to have a *microtome* for cutting paraffin sections and it is very convenient for cutting sections of stems and other things.[1]

Methods for preparing all kinds of botanical material for microscopic study are described in "Methods in Plant Histology," by C. J. Chamberlain.[2]

THALLOPHYTES. ALGAE (Chapter IX)

Ponds, ditches, rivers, and the borders of quiet lakes are good places for most of the fresh water Algae. Many of them can be kept for a long time in the laboratory in gallon battery jars or even in fruit cans. Pour in a little water, occasionally, to replace what is lost by evaporation. Do not add too much water at one time, because many Algae are sensitive to sudden changes in the water. The places where some of the Algae grow are noted in previous chapters.

Blue Green Algae (Cyanophyceae).—Most of the Blue Green Algae thrive better in foul water than in clean water. Look on the surface of the water, suspended in the water, and on stems and sticks in the water. Several forms grow on the underside of Water Lily leaves and on other leaves which float on the water.

Gloeothece.—This Alga is easily kept in the laboratory. Put a long piece of brick—not a glazed brick—in a glass fruit can and pour on water until the brick is nearly covered. Put some of the *Gloeothece* in the water and some on the uncovered part of the brick. Fasten on the lid and the Alga may live and thrive for years.

For study, put a little of the material on a slide, with a very small drop of water, and crush slightly by tapping on the cover glass. Note the cell, which may have a pale bluish green color, and the transparent sheath. The sheath is seen more easily if the light is not too strong. How many cells are there in a group before the cells begin to fall apart? Make drawings

[1] A good microtome is made by the Spencer Lens Co. of Buffalo, N. Y. Slides, covers, and stender dishes can be gotten from the Bausch and Lomb Optical Co., Rochester, N. Y. Stains and reagents can be bought from Coleman and Bell, Norwood, Ohio; or from the National Anilin and Chemical Co., New York, N. Y.

[2] CHAMBERLAIN, C. J., "Methods in Plant Histology," University of Chicago Press.

here and throughout the work. It is often suggested that you sketch this or that; do not limit yourselves to these suggestions but pick out things which seem to be worth drawing.

Oscillatoria.—This is also easily kept in a fruit can in the laboratory. Note how it arranges itself on the side of the can. Make a mount and study the movements which give this genus its name. Look for concave cells and hormogonia. In living material the concave cells are colorless and refractive; in permanent preparations they stain deeply. In your drawings note accurately the comparative length and breadth of the cells.

Anabaena.—This form always has heterocysts and often has spores. Note the dense spot at each end of the heterocyst and the coarsely granular contents of the spore.

Nostoc.—This is the easiest of all Algae to keep in the laboratory. In a fruit can two-thirds full of water and with a tightly fitting top, a culture may be kept for several years without renewing the water.

The sheath of a *Nostoc* filament is very soft and thick and the sheaths of neighboring filaments stick together, so that the filaments seem to be imbedded in a common mass of jelly; but by putting on some iodine or eosin, the separate sheaths can be distinguished. Look for very small *Nostoc* balls with only a few filaments. They are often found in fruit can cultures.

Gloeotrichia.—This is not found so frequently as *Nostoc;* but, unlike *Nostoc,* it usually has spores. Note the long spore with coarsely granular contents. Beyond the long spore is the slender tapering filament which gives the plant the *trich-* part of its name.

Other Blue Green Algae.—Other Blue Green Algae are likely to be found in ponds and ditches, especially where the water looks too bad to drink. Some of them are *Coelosphaerium, Microcystis, Microcoleus, Spirulina, Arthrospira, Tolypothrix, Scytonema, Rivularia, Stigonema,* and *Merismopedia.*

Green Algae (Chlorophyceae).—Most of these grow in cleaner water than the Blue Green Algae. Many are easily kept in battery jars in the laboratory. Many of them are perennial and can be chopped out from the ice in winter. *Cladophora, Oedogonium, Coleochaete,* and the Diatoms are good examples of perennial Algae. The structure is more complex than in the Blue Green Algae. In drawings always note the plastids (chromatophores), nuclei, cell walls, and whether there is a pyrenoid or a sheath.

Pleurococcus.—Note the rather thick wall and look for the nucleus. How many cells may hang together before they begin to fall apart? In many of the Algae, regarded as unicellular, a few cells may hang together for awhile.

Chlamydomonas.—If living material can be found, it will pay to devote to *Chlamydomonas* half the time which can be given to the Green Algae. Note the movements, the cilia, the clear protoplasm at the ciliated end, and the green plastid occupying most of the cell. Can you see the red "eye spot"? Can you see a vacuole near the ciliated end open and close? A vacuole which opens and closes is a *contractile vacuole.* If there are swimming bodies, note whether they are zoospores or gametes.

Volvox.—Sketch a mature colony, a mature colony with young colonies inside. Look for mature eggs and antheridia. Note the rolling movements, if living material is available.

Diatoms.—Study the movements. Do they look like the movements of zoospores or gametes? Note the color and shape of the chromatophores; note the markings on the walls. The markings are seen at their best after the cell contents have been removed. Soak Diatoms or even heat them in hydrochloric acid, then wash in water and mount. It is very easy to make permanent mounts. Simply put the dry Diatoms on a slide, warm it to make sure that it is perfectly dry, and then add a drop of balsam and a cover. If the Diatoms flow to the edge of the cover, use a little of the white of egg mixture used to stick paraffin sections to the slide. Put the Diatoms on the smeared slide, treat with absolute alcohol for five minutes; then xylol, two or three minutes; and then mount in balsam. Fine mounts can be made from diatomaceous earth and from many of the polishing powders.

Spirogyra.—No other Alga affords a better opportunity to practice drawing. If possible, draw, first, one with a single spiral band, then one with two or more bands. Note the bands, pyrenoids, and nucleus with strands of protoplasm stretching from the nucleus to the band. Sketch the two uniting filaments with the zygospores.

Ulothrix.—If you can find living material, watch the zoospores and gametes. They are abundant in the morning up to 10 o'clock; not so abundant from 10 to 12 o'clock; and scarce in the afternoon. Gametes swim faster than zoospores. When gametes come together, it looks as if one gamete were trying to swim in one direction and the other in the opposite direction. The movements are awkward and jerky. The chromatophore is shaped somewhat like a napkin ring. Try to draw it.

Note the pyrenoids and the nucleus. They look alike, but, with a drop of iodine, the pyrenoids take a dark blue or almost black color and the nucleus a light brown.

Oedogonium.—Draw very carefully, noting the shape of the chromatophore in the vegetative cell, and the pyrenoids in the vegetative cell and in the egg. Note the abundant starch in the mature egg. Sketch a holdfast.

Chara.—This Alga is not hard to keep in the laboratory. Put only a little in the jar and let it grow. The jar will hold a great deal in this way; but if much is put in at the start, it will all die. Watch the rapid movement of protoplasm. Make a habit sketch, natural size, and a drawing, on a large scale, showing an oogonium with its spiral covering, and the antheridium, just below. Crush the antheridium under a cover glass and sketch some of the contents. Each of the wavy filaments contains about two hundred sperms.

Brown Algae (Phaeophyceae).—Schools near the ocean can get unlimited material of the Brown Algae at any time. Much will be thrown upon the beach by the waves. Inland schools will depend, largely, upon preserved material. Material can be rolled up in oilcloth, however, wrapped in at least a dozen thicknesses of newspaper, the whole package covered with oilcloth, and sent from either coast to the Mississippi River by parcel post

and arrive in good condition, except in warm weather. It is not satisfactory to send material in sea water. Material preserved in formalin should be soaked in water before it is given to a class. After the study anything worth saving can be put back into the formalin.

Ectocarpus.—Sketch the branching filament, noting the vegetative cell with chromatophore and nucleus. Sketch the sporangia and gametangia. In material collected at any time except during the winter, there will be gametangia but probably no sporangia.

Laminaria.—This is the type of the big Kelps. Sketch the holdfast, stalk, and blade. If there is material, dissect out sporangia. There are many zoospores in each sporangium. Mingled with the sporangia are many sterile filaments.

Fucus.—Fucus can be obtained all the year round and, from November to May, it can be sent safely from either coast to the Mississippi River. Cut sections with a safety razor blade. Also dissect the conceptacles to get out the oogonia and antheridia. Each mature oogonium has eight eggs.

Other Brown Algae.—At the fish market, you may get a Brown Alga, *Ascophyllum,* looking somewhat like *Fucus.* If a miscellaneous lot of Brown Algae has been sent from the Atlantic Coast, it is likely to contain *Fucus, Ascophyllum, Sargassum, Laminaria, Chorda,* and *Ectocarpus.* Small Red Algae may be growing on any of these, especially on *Chorda.* From the northern Pacific Coast there may be *Fucus, Nereocystis, Costaria, Laminaria, Egregia, Ectocarpus,* and others; from the California Coast there may be *Macrocystis, Egregia, Pelvetia,* and *Ectocarpus.*

Red Algae (Rhodophyceae).—The Red Algae are delicate and cannot be sent long distances like the Brown Algae, but they can be allowed to dry in the sun, and then they can be sent in a pasteboard box. When needed for use, soak in water, preferably with a tablespoonful of salt to a quart of water. They will look very much as when first taken from the water. They can be mounted on sheets of paper by placing the sheet of paper on a board in a pan of water and arranging the Alga with toothpicks. Put a piece of cheesecloth over the mount and lay on two or three sheets of absorbent paper. The blotters used in pressing higher plants are all right. Change the blotters three or four times the first day; twice, the second day; and once a day thereafter until the specimens are dry.

Nemalion.—In 10 per cent formalin in sea water this Alga keeps its color for years, if not left in bright light. It can be studied as well from the material as from permanent mounts. Make a habit sketch and then crush small pieces under a cover glass. Most of the carpogonia and trichogynes will be found in the slender filaments. The cystocarps will be everywhere, but the largest ones will be in the larger filaments. The pyrenoid is so large in Nemalion that the student is likely to mistake it for the nucleus and miss the nucleus altogether.

Polysiphonia.—This Alga is found on both coasts and can be gotten within wading depth. Inland schools had better study it from material preserved in 10 per cent formalin in sea water. Make sketches showing the

branching habit, the tetraspores, antheridia, and cystocarps. These three are on different plants. The carpogonia and trichogynes are small and hard to recognize. It would be better to spend the time on something else rather than in hunting for them.

If any of the larger forms are available, like *Rhodymenia*, *Calophyllis*, *Chondrus*, and *Corallina*, make habit sketches.

Review of Algae.—Define Algae, Blue Green Algae, Green Algae, Brown Algae, Red Algae. What forms of reproduction are found in each of these four groups? What forms have isogamous reproductions? Heterogamous? What is the difference between a zoospore and a gamete? What forms have oogonia and antheridia? What ones have no zoospores? What heterogamous forms have no motile spores or motile gametes? What unicellular forms have you studied? What filamentous forms? What fresh-water forms? What salt-water forms?

THALLOPHYTES. FUNGI (Chapter X)

Fungi are not kept in the laboratory for long periods like the Algae. Small hard forms, like *Xylaria*, *Hypoxylon*, and the Bird's Nest Fungi; leathery forms like many of the smaller pore Fungi; and the larger Bracket Fungi, can be kept dry. The Puff Balls and Earth Stars, if they have not rotted, can be kept dry; and all Myxomycetes are kept dry. Cartilaginous forms, like *Clavaria* and the Ear Fungi, and also the soft fleshy Fungi, can be kept in formalin.

Many Fungi can be brought into the laboratory alive and can be thrown out after the study. The Bread Mold, the Green Mold on cheese and leather, and the various Fungi on fruits and vegetables, which can be secured at any time, do not need to be preserved.

Myxomycetes.—*Stemonitis*, *Trichia*, *Physarum*, *Lycogala*, and *Fuligo* are good types for laboratory study. Spores germinate when only a few months old. Few Myxomycete spores will germinate at all after they are a year old.

In any Myxomycete sketch the habit, the capillitium, and the spores. In *Stemonitis* note the columella and the network of capillitium. In *Trichia*, and in many others, note the spiral bands on the capillitium threads.

Try to germinate the spores. From blotting paper cut out two pieces just a little smaller than a microscope slide. If the blotting paper is *very* thick, one piece will be enough. Make a hole about half an inch in diameter in the middle of the blotting paper. Put some spores in a small drop of water on a cover glass and invert the cover glass over the hole in the blotter. Wet the paper. This will provide a "moist chamber" which will serve for several days. The spores may germinate in a couple of hours. If they do not germinate in a couple of days, they will not germinate at all. If the spores germinate, note the *amoeboid* movements and the *hopping* movements. When people look at these movements, they call the Myxomycetes animals; when they look at the sporangia, they call them plants.

Bacteria.—By scraping the inside of the cheek with the finger nail, some Bacteria can almost always be secured and, often, all of the three types,

Bacillus, *Coccus*, and *Spirillum*, will be found. The hay infusion method of getting Bacteria for class study is almost always successful. Pour hot water on a handful of hay and filter the liquid through blotting paper. Put the liquid in a glass dish and cover it to keep out dust. When the liquid begins to look cloudy, Bacteria will be abundant. A rod-shaped form, *Bacterium*, generally comes first, but is soon followed by *Coccus* and *Spirillum*. Mount in a very small drop of water and watch the movements. Dangerous Bacteria, like typhoid, dipththeria, tuberculosis, and anthrax, should never be used in class, except in permanent preparations. The methods of making permanent preparations kill the spores even of the most resistent Bacteria.

Phycomycetes (Alga Fungi).—The most important types to study here are *Saprolegnia* and the Bread Mold.

Saprolegnia.—Dip up water from several places, remembering that water which you would not care to drink is likely to be the best. Throw in a few flies or ants and a few pieces of hard-boiled egg. The pieces of egg should not be more than half as large as a grain of Wheat. It is better to have several dishes and not much material in each. When a halo of Fungus filaments appears around one of the flies or one of the pieces of egg, lift it out and put it into a dish of clean water. When the ends of the filaments look coarse, the sporangium stage has been reached, and there should soon be swimming zoospores. Watch, and you may see zoospores escaping from the sporangium. Look for oogonia and antheridia. They are likely to come a day or two later than sporangia. When you get *Saprolegnia*, you will also get a lot of Bacteria. You can keep the Bacteria down, more or less, by transferring the flies or egg to fresh water every day.

White Rust (*Albugo candida*).—Look on Shepherd's Purse. White shining blisters will be the conidia stage. If the stem is swollen or the pods very much enlarged, a section will show oogonia and antheridia. The conidia soon produce zoospores when placed in water. There are no motile spores of any kind in any of the Fungi beyond this group.

Bread Mold (*Rhizopus*).—Expose a slice of bread to the air for a couple of hours. Sprinkle it with water and cover it with any kind of glass dish. A battery jar or bell jar is good. In a couple of days there should be an abundance of cobwebby mycelium with whitish young sporangia which soon turn black. Mount in water and note the sporangia with long stalks, the brownish rhizoids, and the "runners" connecting groups of sporangia.

There will be no zygospores unless you have two kinds of mycelium, called the "plus" and the "minus" strains. These two strians can be secured from supply companies. If you get them, place the two strains on a piece of bread, about two inches apart. When the two masses of mycelium come together, there will be numerous zygospores along the line of meeting.

A fluffy Mold on Potatoes, Apples, and Pears is likely to be the same one which is so common on bread.

Ascomycetes (Sac Fungi).—Many Ascomycetes are found on rotten wood, many grow on dead dry wood, but many grow on living leaves and other parts of the plant.

Peziza (*Cup Fungus*).—The small red or orange cups are good for study. The larger, fleshy, light brown ones are also good but break up easily when handled. Sketch the habit. Cut a section about half as thick as a piece of blotting paper and crush it under a cover glass. It should show many asci, each with its eight spores. Mingled with the asci there will be numerous sterile filaments.

Green Molds.—The slice of bread with the Bread Mold is likely to show green patches before the end of a week. These will be *Penicillium* or *Aspergillus*. The *Penicillium* is a branching form with rows of spores at the ends of the branches. *Aspergillus* has a stalk with a swollen top from which rows of spores extend in all directions. Expensive cheeses, if they have green spots, will furnish one of these two Fungi. Look on Grapes, spoiled preserves, old leather, and mimeograph pads for material. You are not likely to find the ascus stage.

Morchella.—This Fungus, often called the Morel, is so good to eat that its scientific name is *Morchella esculenta*. If you find it, make a habit sketch. A piece of one of the ridges, about the size of a pinhead, crushed under a cover glass, will show the asci, which are very large.

The Powdery Mildews.—All of these grow on leaves. At first the leaf looks as if dusted with a powder puff. This is due to small spores. Later, little black dots appear. One of these Mildews is very common on Lilac leaves; another, just as common, grows on Knot Weed (*Polygonum aviculare*); another grows on Beggar Ticks (*Bidens frondosa*); one on the Virginia Creeper (*Ampelopsis quinquefolia*) is rather common; another is often found on Willow; and many other leaves have Mildews.

Soak a leaf in water for half an hour and then scrape off some of the mycelium with the black dots (perithecia). Examine under the microscope; then crush the perithecia by tapping on the cover glass and the asci will come out. The *appendages* to the perithecia are very characteristic, but they are brittle and will break off unless the material is well soaked before mounting.

Yeast.—Get this material at the grocery or at the cafeteria. Moisten it and keep it a little above room temperature. It will soon grow. Note the budding. Sketch a cell with nucleus and oil globules.

Imperfect Fungi.—Look on diseased fruits and vegetables and see whether you can find the forms shown in Fig. 184. Sketch what you can find.

Lichens.—In most parts of the country it is easy to find Lichens. Make habit sketches of as many as you can find. The names are not necessary, but the sketches should be labeled Foliose, Fruticose, or Crustose Lichen.

Wet the Lichen and cut as thin sections as possible. Note the positions of the Alga and Fungus. Cut across the fruiting part and note the asci with their ascospores. In many Lichens the ascospore has two or more cells.

All of the Lichens can be kept dry in a box. A few minutes' soaking in water will make them look fresh and they will be easy to handle.

Basidiomycetes (Basidium Fungi).—Many of these forms are so large and familiar that they have common names. Look on Corn, Wheat,

and Oats for Smuts; on Wheat, Oats, and other Grasses for Rusts; in the woods and fields for Mushrooms and Toadstools; in the fields for Puff Balls; and on the sand for Earth Stars.

Smuts.—Sketch the Corn Smut. The great swollen mass may come from a single distorted grain of Corn. The common Sand Bur (*Cenchrus tribuloides*) often has a smut in the flower cluster. It sheds spores in the autumn.

Rusts.—There should be a thorough study of the Wheat Rust. Any part of the country where Wheat and Oats are raised will furnish material of the Red Rust and the Black Rust; but the stage on Barberry is getting scarce. If you cannot find material, try to get it from your nearest agricultural station, or from the Department of Agriculture at Washington. The botanical supply companies are likely to have it.

Make habit sketches of the streaks (sori) of Red and Black Rust. Scrape off the spores (Urediniospores) of the Red Rust, and the spores (teliospores) of the Black Rust. Sketch the orange-colored spots on the Barberry leaf as they appear to the naked eye, and as they appear under a pocket lens. Then look at a section under the microscope. There should be a cluster cup with numerous rows of spores. Try to germinate the teliospores. If they germinate, there will be a short, four-celled tube, the *basidium*, each cell of which should produce a *basidiospore.* Study this life history and read what you can about the damage it does to Wheat, Oats, and other cereals.

Mushrooms and Toadstools.—Sketch any you can find. The one at the grocery is *Agaricus campestris*, the Field Agaric. It is very good to show the stalk, cap, gills, ring, and velum. The basidium has only two spores. In most of the forms you may pick up, the basidium will have four spores, the typical number. If you find a form with a *volva*, sketch it. Forms with a volva are so likely to be poisonous that the volva is called the *death cup.* Many of the poisonous forms have a sharp, pricking taste, but some taste all right. One can bite into a small piece and spit it out with no danger, even in the poisonous ones.

The Bracket Fungi.—Sketch one of the large Bracket Fungi. Cut from the top down to the bottom and note that there have been successive layers of pores. A layer of pores is formed each year. From the underside, sketch a few of the pores as they appear under a hand lens. There are grubs in nearly all of the older specimens. Sketch one of the smaller kinds, like the one shown in Figs. 190, 191. Note the difference in the shape of the pores.

Puff Balls.—If these are collected just before shedding spores and heated in an oven hot enough to dry them rapidly but not hot enough to make them collapse, they can be kept indefinitely in boxes and used time after time. Sketch, natural size. Note the hard, often smooth, outer part and the spongy mass inside. If Earth Stars (*Geaster*) are available, wet them and see the rays of the star spread out. Sections of Puff Balls show the tougher outer part and the much chambered inner part. The basidia line these chambers.

Bird's Nest Fungi.—These can be kept dry in box, just as they are brought in. Sketch, natural size. The "eggs" in the nest are so hard that it is difficult to cut them. The basidia are inside the eggs.

Review of Fungi.—How do Fungi differ from Algae? What is mycelium? What Fungi have no mycelium? Define Myxomycetes, Bacteria, Phycomycetes, Ascomycetes, Basidiomycetes. What Fungi have motile spores? What Fungi have oogonia and antheridia? What Fungi have zygospores? What Fungi have spores inside a sporangium? What Fungi bear their spores exposed? Describe the life history of *Saprolegnia, Albugo, Rhizopus.* Describe *Peziza, Microsphaera.* Give the life history of a Smut, a Rust. Describe a Mushroom, a Puff Ball, a Bracket Fungus, a Bird's Nest Fungus. What is a parasite? A saprophyte? How do Fungi damage plants? How do people try to lessen damages?

BRYOPHYTES (Chapter XI)

Many of the Bryophytes are perennial and, consequently, material can be collected at any time; but their fruiting seasons are limited. Since the plants are small, it is easy to keep a stock in the formalin-acetic-acid preservative. Practically all the Mosses and many of the Liverworts may be kept dry in boxes until needed for use, when they can be brought back to their natural form by soaking in water. Many forms, after being kept dry in boxes for a year or two, begin to grow as soon as they are soaked in water.

LIVERWORTS

It is much easier to make permanent preparations of Liverworts than of Mosses, because the necks of the archegonia of Liverworts do not get so hard and the sporophytes cut easily, even when nearly mature.

Marchantiales.—The largest Liverworts belong here. The most usual forms are *Marchantia, Conocephalus, Riccia,* and *Reboulia.* In greenhouses, *Lunularia,* named for its crescent-shaped cupule full of gemmae, is often abundant.

Riccia.—Look for *Riccia* in early spring. It floats along the borders of ponds and ditches. Antheridia, archegonia, and sporophytes come early in the season. During summer, autumn, and winter, the plant grows at the forward end and keeps dying off behind but does not reproduce. Cut sections of the puffy spring plants and note the spherical sporophyte imbedded in the gametophyte. Note that all the sporophyte, except a thin covering, produces spores.

Marchantia.—This familiar Liverwort fruits early in the spring, but may be found fruiting at almost any time, except in the winter. It is easily raised in the greenhouse or laboratory. Scatter gemmae on flower pots and keep in as bright light as possible. Scrapings from charred wood, scattered on the soil, hasten the growth. Since gemmae from archegonial plants always produce more archegonial plants, and gemmae from antheridial plants produce only antheridial plants, it is easy to get separate patches of

the two kinds of plants; but, to get sporophytes, it is better to have the two kinds mixed.

In *Conocephalus*, the young sporophytes are well advanced when winter arrives. The spores are shed the next spring.

Jungermanniales.—Some of these are flat, like Fern prothallia, but all the leafy Liverworts belong here.

Pellia.—This is a common and widely distributed little Liverwort about as large as one's little finger nail. Antheridia and archegonia come on the same plant in late summer and early autumn. Sporophytes are well advanced when winter sets in, and the spores are shed in the spring. If material is brought into the laboratory in winter, the spores will be shed in a week or two.

Pallavicinia looks like *Pellia*, but has archegonia and antheridia on different plants and has a strong midrib.

Porella.—*Porella* is a leafy Liverwort and is the most satisfactory form to keep for study. It can be put into a pasteboard box and, even after a couple of years, when it is taken out and sprinkled, it begins to grow. Note the two kinds of leaves and the peculiar lobe at the base of each of the larger leaves. Dissect out the antheridia, archegonia, and sporophytes. Note how the sporophyte splits into four parts.

Anthoceros.—This important little Liverwort is found in fruit at almost any time, except during the winter. It does not seem to thrive in the greenhouse but can be kept there on clay soil or shale. When an abundance of it is found, it is worth while to put it into preservative.

In sketches, record the comparative size of sporophyte and gametophyte. In a cross-section of a sporophyte, note that the spores are in a ring around the *columella.* When the spores are shed, the sporophyte splits lengthwise into two pieces. The dried up columella can be seen as a thread between the two pieces.

BRYOPHYTES. MOSSES (Chapter XII)

Practically all the Mosses can be kept dry in boxes and will be in good condition for study as soon as they are soaked a little in warm water. They can be pressed and mounted on paper, like herbarium specimens of the higher plants. For such specimens, do not press too hard. Put the specimens between a couple of sheets of newspaper, put a couple of sheets of absorbent paper above and below, then add more newspaper with material and more absorbent paper, and put on a flat board with a brick to furnish the pressure. Change the absorbent paper—but not the newspaper—three or four times the first day; twice, the second day; and once a day after that until the specimens are dry. The entire study, except the study of sections, can be made from material pressed or put away dry in boxes.

Sphagnum.—Sketch the habit, showing main axis, branches, leaves, and the sporophytes, if available. Sketch a single leaf, showing the long narrow cells which contain the chlorophyll and the large empty cells with the bands. If sporophytes are available, note the *operculum.* The protonema usually looks like a small Fern prothallium. Students seldom find it.

The True Mosses.—*Funaria* is the commonest and most widely distributed type. One finds it even along the streets and sidewalks of a big city. Green patches on bare soil, looking like *Vaucheria*, should be examined, because they may be the protonema stage of the Moss. Scrape off the green material, with a very thin layer of soil, not more than $\frac{1}{16}$ inch thick. Put a piece in the palm of the hand, hold it under a small stream of water from the tap, and stroke it gently with the finger of the other hand. Most of the soil can be removed in this way. Material cleaned in this way can be put into 25 per cent glycerine in an open dish and left until the glycerine is as thick as pure glycerine. This perserves the natural color and the material will keep indefinitely. Of course, permanent mounts can be made from such material, either in glycerine or in glycerine Jelly.

Note the branching and young plants coming from the protonema. As the leafy plants develop, there will be brown protonema with oblique cross-walls and there will be rhizoids coming from the young plants. Dissect out archegonia and antheridia and make sketches. In young plants, especially of *Funaria*, note how immensely the archegonium stretches as the young sporophyte develops. When the archegonium breaks, the part which is carried up, with the neck of the archegonium at the top, is the *calyptra* (cover). In late stages of the sporophyte, after it turns yellowish or brown, pick off the operculum with a needle. Sketch it. Sketch the peristome in bird's-eye view. In *Funaria* it will have 16 teeth arranged like the spokes of a wheel. Lay the sporophyte down on its side and cut off the peristome. Look at it from above and below. Note the small spores and try to germinate them in water. They are likely to germinate unless the spores are more than two years old. If they germinate, they will produce protonema.

Make habit sketches of leaves of any Mosses you can find, especially *Polytrichum, Atrichum, Leucobryum, Fissidens, Funaria, Mnium*, and *Bryum*. Sketch the sporophyte, with calyptra, of *Polytrichum, Atrichum*, and *Climacium*.

Mosses are not easy to section, but the most important things, which should be learned first, can be studied without sections.

PTERIDOPHYTES (Chapter XIII)

Many of the Pteridophytes can be found in greenhouses all the year round, especially the Ferns. Living material is always desirable, but leaves and even whole plants can be pressed.

Lycopodiales.—Three out of the four genera of Lycopodiales grow in the United States, but only one of them, *Lycopodium*, is common.

Lycopodium.—*Lycopodium* is perennial and material can be gotten, even in winter, if one knows where to clear away the snow. Those who are not in *Lycopodium* localities can have this form sent to them and can press it, as directed for Mosses. It should not be pressed hard enough to flatten the specimens very much and the cones should not be flattened at all. Well-pressed specimens keep their color and are just as good for class use as preserved material.

Make a careful habit drawing. Is there a rhizome? Does the plant branch? Are the leaves spiral or cyclic? Sketch the cone. Make a sketch of a sporophyll with its sporangium.

Cut a cross-section of the stem and sketch the cortex and woody region. Note that in most species the wood is in bands, with the phloem between them. *Lycopodium* has an exarch stele with several protoxylem groups, each with a large number of small cells.

You are not likely to find any prothallia or to germinate the spores.

Selaginella.—Nearly all of the hundreds of species of *Selaginella* are tropical and the few which grow in the United States are not abundant. *Selaginella apus* is a very small form growing in wet places. It has large sporangia and spores and is good for study, if you can get it. *Selaginella rupestris* grows in dry, rocky, or sandy places. Several species are kept in greenhouses. The trailing forms, so popular for mossy carpets, seldom have cones; but those which have their leaves in rosettes are likely to have cones all the time. In places where it is not possible to get *Selaginella* all the time, it should be preserved in the formalin-acetic-acid mixture.

Sketch the habit of the plant; note the profuse branching which takes place so that a series of branches, in one plane, looks like a compound leaf. The leaves of *Selaginella* are small and simple with a midrib but no side branches. Note the two kinds of leaves. Sketch a cone. Dissect off some sporophylls and sketch them with their sporangia. The megasporangia are whitish or yellowish; the microsporangia are likely to be reddish. How many microspores are there in a microsporangium? How many megaspores in a megasporangium? How do the two kinds of spores compare in size?

If there are sections, note that the mature megaspores have many cells inside, these cells constituting the female gametophyte. After the megaspores have been shed from the megasporangium, the archegonia may be seen through the three-rayed crack in the megaspore coat. On the flower pots and on greenhouse benches you may find small sporelings with their two cotyledons.

Isoetes.—This form is not likely to be abundant and it looks so much like a Grass that it is easily overlooked. It can be kept in a tank in the greenhouse, but it is better to keep a reserve supply in the formalin-acetic-acid mixture. It is hardly worth while to press it or to keep it dry in boxes.

Sketch the habit, showing the very short stem with roots and long round leaves. Cut a cross-section of a leaf and note the four large air cavities. In a cross-section of the stem, note the central part and the cortex with its prominent leaf traces. This is the only living Lycopod in which you are likely to see any secondary wood. Cut longitudinal sections of the lower part of megasporophylls and microsporophylls with their megasporangia and microsporangia. The megaspores can be seen with the naked eye. Note the strands (called *trabeculae*) which look like partitions in both kinds of sporangia. Compare the size of megaspores and microspores. Both are shed in the uninucleate condition; so, anything beyond the one-celled stage in either of the gametophytes must be gotten by germinating the spores

after they have been shed. They remain alive for at least a year after shedding and can be germinated in water.

PTERIDOPHYTES. EQUISETUM (Chapter XIV)

Equisetum is widely distributed and in many places is very abundant. The commonest form is *Equisetum arvense*, which has rather large cones on soft yellowish stalks early in the spring. As these die, green branching shoots appear and last until winter. The rhizome, with new cones and buds, survives the winter. It is best to preserve the soft shoot and cones in the formalin-acetic-acid mixture. Dig it up, carefully, just before the spores are shed, selecting a short piece of rhizome, with the soft shoot and cone, and the bud which is to make the green summer shoot. Material collected in the autumn shows the mature summer form and—underground—the cone which is to appear above ground the next spring.

Other species, with little or no branching and with the cone on the end of the summer shoot, have cones later in the season. *Equisetum hyemale* is green all winter and is widely distributed.

Make a habit sketch of the whole plant, with rhizome, roots, and upright stem. On a larger scale, sketch a part of the stem, showing the reduced leaves. Sketch the position of stomata, as they appear under a pocket lens. Make a cross-section of the stem and sketch the central cavity and the carinal and vallecular cavities. If you have living material, sketch the position of the chlorophyll. Draw a cone very accurately; draw a sporophyll with its sporangia. When the spores are shedding, put some on a slide and wet them a little. Note the movements. Spores, at the shedding stage, can be kept dry and will show these movements even after staying in a box for years. The spores germinate readily as soon as shed, but will not germinate a month later. Sow them on wet sand. If you can keep them alive for three weeks, there may be antheridia. Before they are old enough to have archegonia, they generally die from the attacks of Fungi or Blue Green Algae. Wetting them with a solution of permanganate of potash may keep down infection without killing the prothallia.

PTERIDOPHYTES. FERNS (Chapter XV)

Ferns are always available in greenhouses. In any forest there will be some kinds of Ferns. The Cinnamon Fern, Sensitive Fern, and some of the Shield Ferns grow in wet swampy places. The Bracken Fern, Maiden Hair Fern, Christmas Fern, and others grow where it is not so wet.

Leaves with sori of sporangia can be pressed lightly with frequent change of blotters. It will not be necessary to wet them for study. Stems for sections should be preserved in the formalin-acetic-acid mixture. Prothallia and young sporelings are so easily raised that it is hardly worth while to preserve them. They keep well, however, in the formalin-acetic -acid mixture.

The Leaf.—Sketch leaves of a few Ferns. Sketch leaflets showing the veins. Forking veins are characteristic of Ferns. The Maiden Hair Fern, Boston Fern, Christmas Fern, and Bracken Fern are good examples.

The Stem.—Ferns afford the best opportunity for beginning a study of the conducting system of plants. The vascular system is called the *stele.* The different kinds of stele are described in the text. The best protostele will be found in *Gleichenia.* It is tropical but can be had from supply companies. The Maiden Hair Fern and the Hay Scented Fern show the *amphiphloic siphonostele.* The Cinnamon Fern and the Royal Fern have an *ectophloic siphonostele.* The Bracken Fern, *Polypodium,* and many others have a *polystele.*

Make sketches of the different kinds of stele, showing the position of xylem, phloem, and cortex. Make a drawing of a cross-section of a single bundle, showing the cells accurately. Make a drawing of a longitudinal section showing a *scalariform tracheid.* This tracheid, with its ladder-like (scalariform) marking, is the most characteristic woody cell in Pteridophytes.

Most Ferns have mesarch protoxylem. One, two, or three groups of small cells in each bundle are likely to be the protoxylem. In an immature bundle, stained with Safranin and Gentian Violet, the protoxylem stains red and the rest of the xylem (metaxylem) stains violet. When the bundle is mature, all of the xylem stains red. In the Maiden Hair Fern note the leaf gaps and leaf traces.

The Root.—The Grape Fern is particularly good for a study of the root. Cut a cross-section. The stele is *radial* with four or five rays. The protoxylem is exarch at the tips of the rays, and the phloem is between the rays. All roots have exarch protoxylem.

The Sporangium.—Where living material is not at hand, well-pressed material is almost as good. Sketch different types of sori. The Bracken Fern and greenhouse species of *Pteris,* the Maiden Hair Fern, any species of Shield Fern, any Spleenwort, and a *Polypodium* make a good series. The tropical Fern, *Cyrtomium,* very common in greenhouses and easiest of all Ferns to keep in the house, which has a large, umbrella-shaped indusium, is a good example of the shield type.

Scrape off sporangia and examine them under a microscope. Sketch a sporangium, showing the position of the annulus. Note that the spores are all of one size. Cut a section through a sorus, perpendicular to the leaf. Use the Shield Fern, if you have it. Note the arrangement of sporangia under the indusium. The younger sporangia are protected under the indusium, while the older ones are pushing out to shed their spores.

The Gametophyte.—One can usually find gametophytes (prothallia) in various stages on pots in the greenhouse. They are easily grown by sowing spores on rich soil on pots in the greenhouse. Be sure that you are not sowing sporangia which have already shed their spores. Keep the pot covered with a pane of glass. The following is an ideal way to raise immense numbers of prothallia: Take a new four-inch flower pot, as porous as possible; fill it with wet Peat Moss; invert it in a plate or dish of water so that the lower part of the pot is covered for about an inch. Wet the outside of the pot and scatter spores on it; cover the pot with a battery jar or bell jar. *Pteris longifolia,* a common greenhouse Fern is good because the prothallia develop so rapidly. As the water in the dish evaporates, renew

it; but it will not be necessary to water the pot with the spores on it. In less than a month there should be antheridia. Mount prothallia on a slide in a drop of water and look for swimming sperms. Archegonia come a week or two later. By the end of six weeks there should be many small sporelings. Make sketches of mature prothallia with antheridia, archegonia, and sporelings.

Paraffin sections are necessary to get good views of the internal structure of the antheridia, archegonia, and young embryos.

The Water Ferns.—These are seldom studied in beginning classes, but in one of these Ferns, *Marsilia*, it is so easy to get swimming sperms that this feature should be observed. Sporocarps, kept for many years, germinate promptly when cut open and put into a dish of water. A gelatinous ring comes out in a few minutes and on the ring are many sori. With the naked eye one can see the large megaspores. The much smaller microspores are barely visible but can be seen easily with a pocket lens. Within 24 hours sperms may be seen swimming vigorously. The sperm is coiled like a corkscrew. The archegonium will be seen as a small elevation at the top of the megaspores, and many sperms stick on the transparent mucilage over the top of the archegonium. In a few days, small green sporelings will be abundant. If some soil be put in the bottom of the dish, the sporelings should grow.

SPERMATOPHYTES. SEED PLANTS (Chapter XVI)

In the Seed Plants something can be secured in the living condition at all times of the year; but it is worth while to consider how much time shall be devoted to Gymnosperms and to Angiosperms and to decide, a year in advance, just what material is desirable. Then find out what can be secured in the living condition when it is needed, what should be pressed, and what should be put into preservative. Teachers going to a new school in the autumn may find it hard to get certain things and may have to depend upon supply companies for many things which they could collect for a second year. In some schools teachers are so burdened with teaching and reports that there is little time for collecting, and few teachers have time for making permanent preparations; but some of the more able and ambitious students can be taught to make slides, and a permanent teaching equipment can be built up gradually.

GYMNOSPERMS

Some of the material can be kept dry, but some had better be preserved in the formalin-acetic-acid mixture.

Cycadophytes.—The lower members of this group, the Seed Ferns and Fossil Cycads, are generally represented in the geological section of a city museum. Lantern slides showing the fernlike leaves of the Seed Ferns and the trunks of the Fossil Cycads are almost as good as the fossil specimens.

The living Cycads are represented in most park conservatories by the Sago Palm (*Cycas revoluta*) and often by others. Note the fernlike habit of the plant. Compare the leaves with the leaves of Ferns. If male cones

or even sporophylls from them are available, note that the sporangia are on the underside and that the sporangia are in groups (sori) as in Ferns. If megasporophylls are available, note that the seeds are borne on the sides of the sporophylls. The remote ancestors of the living Cycads were Ferns, and the Cycads still retain many Fern characters. The megasporophyll of *Cycas*, looking more or less like a leaf, is an ideal *carpel;* and the exposed seeds on its margins make an ideal illustration of the "naked seeds" of the Gymnosperms. The Angiosperm ovary is made up of such carpels which have lost all or nearly all of the leafy appearance and have their edges turned in and grown together so as to enclose the seeds.

Lantern slides of living Cycads as they appear in the field make this ancient group seem more real.

Coniferophytes.—Lantern slides of Pines, Firs, Spruces, Junipers, and the Big Trees make a good introduction to this group, especially in parts of the country where there are few Gymnosperms.

Leaves.—It is best to have living material. At Christmas time most of the Christmas trees are Spruce (*Picea*); some are Fir (*Abies*), and a few are Pine (*Pinus*). If the study of Gymnosperms comes after the holidays, and there is no living material in the neighborhood, preserve some of the branches in the formalin-acetic-acid mixture; or put small branches into boiling water for about one minute, to keep the leaves from falling off. The branches can then be kept dry.

Sketch a small piece of branch of Spruce or Fir with a few leaves. Compare the flattish branch of Arbor Vitae. Sketch a spur shoot of Pine with its two, three, or five leaves. Make a cross-section of a Pine needle and sketch the two bundles with the colorless cells around them. Note also the green cells outside the bundle area, the thick-walled cells just beneath the epidermis, the resin canals, and the stomata.

In leaves of the Maiden Hair Tree (*Ginkgo*), note the regular forking of the veins. There are two veins in the leaf stalk. A branch from one of them supplies one-half of the leaf blade and branches from the other supply the other half. Try to follow this branching.

The Stem.—Cut a cross-section of a Pine or any other Gymnosperm about as large as a lead pencil. Note the pith, woody region, cambium, phloem, and cortex. How many annual rings are there? Note position of resin canals. Draw, very carefully, a small piece two or three cells wide, showing the rings.

From a piece of White Pine, cut cross, longitudinal radial, and longitudinal tangential sections. Make drawings from all three. Note the tracheids with bordered pits, the pith ray, and any resin canals.

The Roots.—Make a cross-section of a small root about one-eighth of an inch in diameter. Sketch the wood, phloem, and cortex. Is there any pith? Are there any annual rings?

The Flower.—For habit study, cones may be kept in the formalin-acetic-acid mixture. Mature ovulate cones, before they crack open, can be kept dry. After they crack open, they are hard to draw. Staminate cones, just before shedding their pollen, should be kept in the preservative.

Make a habit sketch of a staminate cone. The microsporophylls look as if they were arranged in vertical rows, like grains of corn on a cob, but the arrangement is really spiral. Dissect the cone and sketch a microsporophyll with its microsporangia. In Pine there will be two microsporangia; in Juniper there will be more. Sketch a pollen grain of Pine, showing the wings. If sections are available, sketch a section of a pollen grain, showing two prothallial cells, the generative cell, and the tube nucleus. Sketch the pollen tube as it grows down through the top of the ovule toward the eggs in the female gametophytes.

Sketch an ovulate cone of a Pine. The arrangement is spiral. Dissect the cone. Note the bract and the ovuliferous scale bearing two ovules. In the Douglas Fir the bract projects, looking like the nock end of an arrow. In a longitudinal section of an ovule shortly before fertilization (about June 10, in *Pinus Banksiana* and June 20 in *Pinus laricio*), note the integument, nucellus (megasporangium) with pollen tubes, and female gametophyte with nearly mature eggs.

Fertilization.—This can be seen only in exceptionally good preparations. One is not likely to recognize it in material cut free hand.

The Embryo and Seedling.—The young stages can be seen in sections cut free hand, but well-stained sections are better. The older stages are studied better in fresh material. The Nut Pine (*Pinus edulis*) can often be bought on the market. Take off the seed coat and dissect the embryo out from the white endosperm. Note the number of cotyledons. Germinate the seeds. The seeds of the Nut Pine germinate readily the first year, and many of them will germinate even after two years. Note how the seed is carried up at the tips of the cotyledons.

Note that in the Pine the first leaves come directly from the stem. Spur shoots, bearing two, three, or five needles come later in the axils of the first kind of leaves. If you can get seeds, try to germinate the Spruce, Fir, Arbor Vitae, Juniper, and Larch. In the Spruce and Fir there is only one kind of leaf throughout the life of the plant. In the rest the first kind of leaf is followed by another kind. In the Juniper (*Juniperus virginiana*) and Arbor Vitae (*Thuja occidentalis*), the first type of leaf, which is needle shaped, is followed by much flattened leaves; in the rest the needle leaf is followed by a spur. bearing the second type of leaf.

SPERMATOPHYTES. ANGIOSPERMS (Chapter XVII)

Before proceeding with the life history of the Angiosperms, it is worth while to stop at this point for a study of the cell, with its cell wall, nucleus, protoplasm, and other contents.

The Cell.—Study living cells in thin leaves of Liverworts, Mosses, or Fern prothallia. Note the nearly colorless nucleus. The protoplasm is also nearly colorless. The plastids (chromatophores) will be easy to observe. They are imbedded in the colorless protoplasm. Watch the movements of protoplasm in the thin leaves of *Elodea*. The movements will be more vigorous in the midrib region. Try *Chara* and any other favorable material. Study starch grains in the Potato.

Study the division of the nucleus and the cell in sections of a root tip. Put an Onion, about as large as a Peach, into a dish of water. When the roots are half an inch long, cut sections with a safety razor blade. Some things can be seen in the living condition; but well-stained sections are necessary for a satisfactory study.

Sketch a cell, with its cell wall, resting nucleus, and protoplasm. Sketch stages in the division of the nucleus. Sketch the earliest appearance of the new cross-wall.

Angiosperms.—It is necessary to decide how much time can be given to this group and to find out what material can be had fresh, what should be pressed, what should be put into a preservative, and what permanent slides are desirable. Even in the colder states, many of the trees and spring flowers will be in blossom when the Angiosperms are reached.

The Leaf.—Leaves are so easily pressed that types which will not be available in the living condition should be pressed and kept dry. Lilac, Catnip, Poplar, Elm, Beech, Maples, Oaks, and some compound leaves, like Locust, Hickory, Walnut, and Horse Chestnut, should be ready, either fresh or pressed. Similar types will be just as good, if the ones mentioned are not available.

Sketch the outlines and veins of several leaves, noting the relation of the veins to the outlines of the leaf. Strip off epidermis and note the stomata. Cut sections and note the upper and lower epidermis, the palisade (when present), and the pulpy lower part. Dissect large buds and study the young leaves. Cut across various buds and note how the leaves are folded in the bud.

Protoxylem is easily observed in leaves. Cut from a *Geranium* leaf, or some other leaf with strong veins, a piece about a quarter of an inch wide and an inch long. The piece should be cut parallel with a strong vein. Then cut in on both sides, down to the vein, break the vein gently, and pull the two pieces apart. The spirals between the two pieces will be the protoxylem.

The Stem.—Study twigs. Note the bud scales and leaf scars. How can you determine the age of a twig? Cut cross-sections of a *Geranium* stem at various levels. Sketch pith, wood, cambium, phloem, cortex, with a band of thick-walled cells near the phloem, pith rays, and epidermis with hairs. Where is the protoxylem? Note fasicular and interfasicular cambium. Sketch, under a high power, a single bundle, showing cells of xylem, cambium, and phloem. Sketch a small portion at the outside, showing epidermis, cork cambium, and cork. Sketch a cross-section of Corn stem, showing scattered bundles (polystele). Draw a single bundle, showing all the cells. From a Pumpkin vine, or some other vine in the Pumpkin Family, draw a sieve tube and a sieve plate.

From a cross-section of Oak, as you see it on the end of a board or, better still, a stump, make a sketch showing annual rings and the large pith rays. From a thin cross-section sketch a small piece showing vessels in the spring wood and cells of smaller diameter in the summer wood. Also note the prominent pith rays.

Take a short piece of Oak board, about six inches long, and split it parallel with the pith rays; then split not quite parallel with the pith rays. These are the directions of the cuts in quarter-sawed Oak. Note the spring and autumn wood in the quarter-sawed surface and also in boards or any Oak furniture. Can you pick out the spring and autumn wood in Oak furniture, no matter in what direction the cut has been made? You should be able to do it if you have studied the split board.

Try to interpret the grain in other wood. It is all the same; but few timbers have such large pith rays as Oak, and, consequently, the quarter-sawed feature is not so striking.

The Root.—Sketch the tip of a root from the section used for a study of cell division. Sketch the elongated cells at the center which are to become the vascular system; the cells outside these, which are the cortex; and outside the cortex, the epidermis. At the extreme tip is the root cap.

Germinate seeds of Corn and Bean so that the tip of the root will be underwater and part of the root will be out of water. Note the distribution of root hairs. Repeat the experiments described in Chap. III. Sketch the origin of secondary roots in the Bean. Sketch adventitious roots in any available forms. Orchids, Screw Pines, and Aroids with adventitious roots will be found in greenhouses.

The Flower.—For habit study it is better to use almost any flower fresh than to use pickled material. *Trillium* is good for habit study of sepals, petals, stamens, and pistil. The Lily is even better, except that the floral leaves are alike, the outer ones, which have the position of sepals, being just like the petals.

For development of the flower use the Buttercup, Strawberry, and Shepherd's Purse. Use Fleabane or Dandelion for the Sunflower type. The garden Sunflower shows the parts on such a large scale that satisfactory sections showing floral development can be cut with a safety razor blade held in the hand. In all cases, note that the sepal, petal, stamen, and carpel, when they first appear, look alike, and look like young leaves or young branches. Cut cross-sections of young anthers, showing the four microsporangia. In forms with large microspore mother cells, like the Lily, the nucleus and even its division can be seen by cutting a rather thick section and crushing it a little under the cover glass. After such a study one will appreciate a thin well-stained section.

Study sections of pollen grains just ready to be shed. Note the exine, intine, tube nucleus, and generative cell. If the generative nucleus has divided, as in the Sunflower, there will be two sperm nuclei and a tube nucleus.

In a Lily, about two days after pollination, cut a ring around the style, about one-third of the way through, and break the style gently. If the pollen tubes are growing well, they will appear as silky strands between the two pieces. Try it with *Iris*, Evening Primrose, or other available material.

Young ovules are easily studied in cross-sections of Lily ovaries. The megaspore mother cell can be seen in fresh sections. The four megaspores of the Lily are not separated by cell walls and so do not look like spores. In

Fleabane the four megaspores are in a row, but they are so small that it is necessary to have thin well-stained sections to get a good view of them.

The embryo sac can be studied in *Aster* or Sunflower. Sketch the outline of the embryo sac, with the egg, synergids, endosperm nucleus, and antipodal cells. The Lily is not so good for this stage, because the synergids are not very clear.

Fertilization.—For this stage the Lily is the best material. Study carefully in a well-stained preparation, for this is the best place in the whole plant kingdom to observe fertilization. Make your best drawing, showing the union of male and female nuclei in the egg, and the triple fusion (fusion of the two polar nuclei and the second male nucleus) which is to start the endosperm.

Embryo and Endosperm.—Study several stages in the development of the embryo in Shepherd's Purse and note the corresponding stages in the endosperm. Note that at first the embryo is nearly spherical. Then the two cotyledons appear and, when the seed is nearly ripe, the stem tip can be seen as a little rounded elevation between the cotyledons.

Note that the endosperm, for a while, consists of a large number of nuclei in a common mass of protoplasm, without any cell walls, the walls appearing only when the seed is nearly ripe. In the *Aster* or Sunflower, the walls appear while the embryo consists of only a few cells.

Most of the edible part of the Coconut, Corn, Wheat, and Hazel Nut is endosperm. In Beans and many others the endosperm has been absorbed by the growing embryo, especially by the cotyledons, so that the edible part is mostly cotyledons.

Seeds and Seedlings.—In mature seeds, note the embryo imbedded in the endosperm in forms like the Morning Glory, *Iris*, Lily, and Sunflower. In Corn and other cereals look for the embryo at one side of the endosperm. The thick fleshy cotyledon of Corn is pressed against the endosperm. In the Bean note that the endosperm has disappeared. Open the seed and sketch the two cotyledons, root, stem tip, and first leaves.

Germinate seeds of the Bean, Pea, Flax, Oak, Basswood, Poplar, Apple, Peach, Orange, Lemon, Grapefruit, Mustard, Date, Corn, Wheat, and any others which may be available. Note the cotyledons, stem tip, and first leaves. Which seeds stay below ground and which are carried up? In which ones do the cotyledons resemble the first leaves, and in which ones are they different? If the stem of a Bean seedling is cut off an inch above the cotyledons, what happens?

The Fruit.—Study any available material. Pumpkin, Squash, Watermelon, Cucumber, Apple, Peach, Pear, Cherry, Orange, Lemon, Grapefruit, Bean, Chestnut, Buckeye, Hickory Nut, Walnut, Hazel Nut, Coconut, Strawberry, Gooseberry, Pineapple, and Artichoke may be suggested. Whatever is at hand will be worth a careful study. In all cases, try to find what parts of the flower take part in the formation of the fruit.

INDEX

(References in **boldface** type indicate pages on which illustrations appear)